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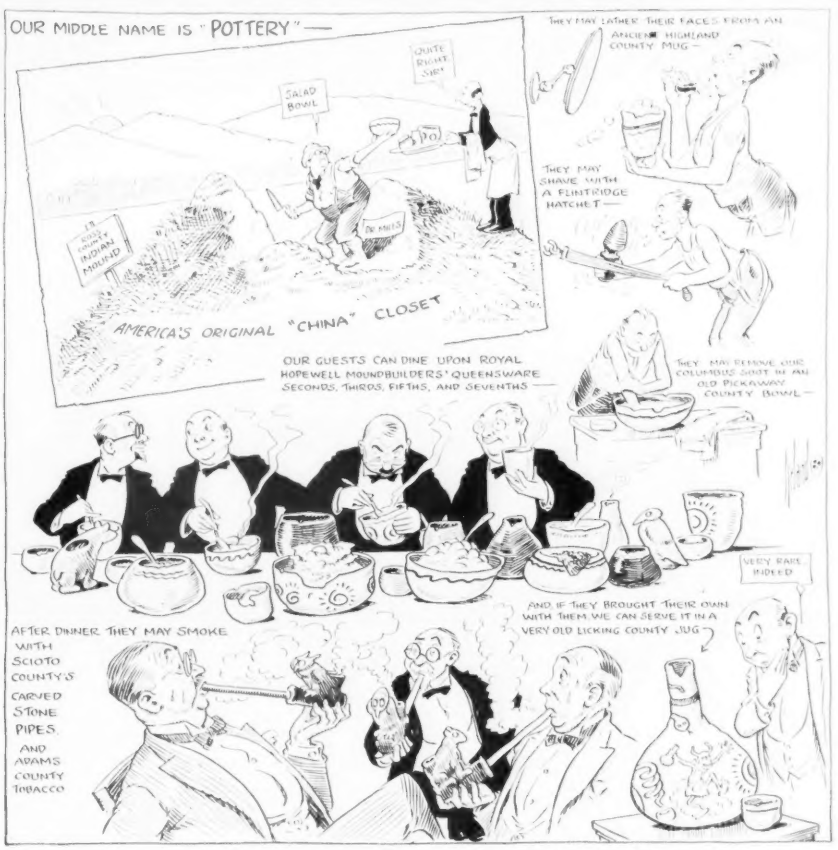
OF THE

AMERICAN CERAMIC SOCIETY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The Annual Meeting of the American Ceramic Society will be held March 29 to April 4, 1936, when motoring is pleasant and June-berry, hepatica, and spicebush are in bloom in Columbus, Ohio, the central location which has been chosen for the meeting. (See page 184.)

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of Technical, Scientific, and Art Questions

Vol. 14 May, 1935 No. 5

PAPERS

THE PHYSICS AND CHEMISTRY OF FIRING CERAMIC WARE*

By J. B. Austin

Abstract

A review of the objectives of the firing process interpreted in terms of the basic chemical reactions occurring during the firing of ceramic ware and of the fundamental laws of heat flow applicable to such a process is presented.

I. Introduction

The object of firing clayware is to produce from a dried shape a finished product possessing strength, form, and such general or particular properties as fit it for its subsequent duties. Since the properties desired differ for different kinds of ware, and since clayware materials show considerable differences in behavior during firing, it would appear at first thought that the firing process is not one which can be described in general terms. All of the changes which may take place during firing are, however, subject to the established principles of chemistry and physics, so that by considering them from this point of view it is possible to correlate them and to derive some useful generalizations. Although the details of a specific application must be considered separately, the general method remains the same in all cases.

II. Reactions Involved

The first step is to list and classify the chief reactions involved. This has been done in Table I which gives them in the approximate order in which they appear in the process. The customary division into periods has been retained as a convenience, although it is purely arbitrary, as shown by the temperature scale in the table which gives the temperature ranges in which the several reactions occur. Cooling has been included since it is an essential part of the firing process and as such must be taken into consideration.

The details of these reactions are so well-known that there is no need to describe them here. Instead, we shall proceed to the important questions: Under what conditions are these reactions possible, how far can they be made to go, if they are possible, and at what speed do they go on? The answers to these questions are to be found (1) in the equilibrium conditions for the reaction in question, which set the limits beyond which the reaction can not be made to go at a given temperature, or the temperature which must be attained before reaction will occur; and (2) in the specific rate of reaction, that is, in the rate at which the reaction proceeds toward equilibrium. Obviously, many of these reactions never reach equilibrium under normal operation of a kiln, but even in these cases the equilibrium data are useful in telling us which way the reactions tend to go.

Since the success of the firing process depends upon the extent to which the foregoing reactions can be controlled, it is worth while to determine and to study means of controlling the factors which influence their end result. The most important of these factors are given in the second part of Table I and our discussion of the chemistry of firing will consist largely in considering the

* This paper is part of a Symposium on Ceramic Ware Firing presented at the Annual Meeting, American Ceramic Society, Buffalo, N. Y., February, 1935 (General Session). Received February 27, 1935.

effect of these variables on specific reactions. The conclusions drawn on this basis are, of course, concerned chiefly with the ware itself and may have to be slightly, though not seriously, modified by limitations of practical operation.

which the equilibrium vapor pressure of the water in the ware is greater than the partial pressure of water in the furnace atmosphere. And other things being equal, the rate of removal is greater, the greater the excess of vapor pressure in the ware

REACTIONS OCCURRING IN CERAMIC WARE DURING FIRING

FACTORS INFLUENCING END RESULTS OF FOREGOING REACTIONS

A. EQUILIBRIUM STATE OF THE REACTION

1. TEMPERATURE

2. COMPOSITION BOTH OF WARE AND OF FURNACE GASES

B. RATE OF REACTION IN THE WARE

1. EFFECTIVE TEMPERATURE

2. COMPOSITION

3. SIZE OR CONDITION OF SOLID PARTICLES

Table I.

III. Removal of Water

(1) Mechanical and Hygroscopic Water

It would be desirable if the ware to be fired contained no water at all, but since this ideal condition is hardly attainable in practice it becomes necessary to consider the effect of the presence of water. In order to remove it, it is obvious that the temperature must be raised to a point at over that in the atmosphere. It is necessary, therefore, to keep the partial pressure of water-vapor in the furnace gases to a low value, which in practice means that the water evaporated must be quickly removed. This requires not only that there be a rapid removal of the furnace gases but that there be a turbulent circulation; for the effective portion of the atmosphere is the small layer of gas in immediate contact with the surface of the ware,

and this layer is undisturbed except by relatively violent agitation of the bulk of the gas, particularly if the shape of the ware is irregular.

Another reason for removing water-vapor quickly is to prevent condensation in the cooler parts of the kiln. The water evaporated from the warmer parts of the setting, unless rapidly drawn away, is likely to condense on the cooler sections, impeding the rate of temperature rise in these sections with the result that during the subsequent firing different portions of the kiln follow different time-temperature schedules, thereby making close control of the operation more difficult. Differences in the water content of the ware in different parts of the setting also result in differences in the rate of increase of temperature. Moreover, the deposition of moisture on cool portions of the ware may lead to the formation of unsightly iron patches at a later stage, since the kiln atmosphere always contains sulfur which, dissolving in the deposited moisture, may react with the compounds of iron and calcium in the ware, forming products that decompose at higher temperatures to give patches. The best method of preventing condensation would be to have uniform temperature through the kiln, a condition which is highly desirable for many reasons, but which is hard to attain in practice, particularly in the early stages of firing.

The rate of evaporation of water is clearly limited by the rate at which the heat of evaporation can be supplied to the place where evaporation is going on and by the rate at which the water-vapor actually diffuses to the surface of the ware. The latter factor is probably the controlling one even with relatively high porosity and becomes increasingly important as the thickness of the ware increases. As a brief digression, it should be noted here that what is required at this stage is a large amount of low-temperature heat; hence it is inefficient to try to push heat in with a high-temperature flame.

In addition to maintaining a uniform surface temperature for all of the ware, it is also desirable that the distribution of temperature within the ware be as uniform as possible; in other words, that the thermal gradients through each piece of ware should be kept to a minimum. For, aside from the stresses which always accompany such a gradient, a condition of this sort implies a rapid or nonuniform heating of the ware with a consequent rapid local evolution of water-vapor. Since under atmospheric pressure the volume occupied by water-vapor is more than 1000 times the volume occupied by the same weight of liquid water, the sudden vaporization of a small amount of liquid may seriously damage the ware.

From the discussion just outlined it may be concluded that the best conditions for firing during the water-smoking period are (1) a minimum of water in the ware, (2) rapid circulation of the kiln gases to remove water-vapor promptly, and (3) uniform temperature distribution throughout the kiln and within the ware.

(2) Water of Constitution

There is no sharp distinction between water held hygroscopically and that usually regarded as part of the constitution of clay, and there is very little difference in their behavior during firing except that the latter is, in general, given off at temperatures of 400°C or upward, which is somewhat above the temperature required to remove the former. This means that even at temperatures above 400°C the furnace gases contain some water-vapor which may influence the course of the oxidation reactions considered in the next section. Aside from this point, the discussion given for mechanically held water applies, *mutatis mutandis*, to water of constitution.

IV. Oxidation and Reduction Reactions

The question as to whether the kiln gases are oxidizing or reducing to iron compounds and organic matter at the start of firing is of relatively little consequence because the rate of these reactions does not ordinarily become appreciable until the temperature has reached 400°C or above. But from this temperature region on, the rate increases rapidly, in many cases nearly doubling for a rise of 10°C. The composition of the iron oxide which forms during this period depends upon the amount of oxygen available, on the steam remaining in the ware and in the kiln gases, and on the temperature. In a limited supply of oxygen, steam, or carbon dioxide, ferrous oxide is stable; while under strongly oxidizing conditions with air, steam, or carbon dioxide, either ferric oxide or magnetite will form. Although under proper conditions steam may be valuable as an oxidizing agent it is always a potential source of a reducing agent and its presence, is on the whole, undesirable. This fact is illustrated by the equilibrium data for the system

iron–hydrogen–water-vapor which are shown by the solid line in Fig. 1. At a given temperature any mixture of steam and hydrogen represented by a point above the line *ABC* is oxidizing to both iron and FeO, while all mixtures represented by points below the line will be reducing to Fe_3O_4. At 600°C approximately 30% H_2O is sufficient to give an oxidizing mixture, but the equilibrium changes rapidly with temperature so that at 800°C about 70% is required. In the atmosphere of the kiln itself such changes are not of great consequence; but in the interior of the ware the evaporation of water may lead to a local concentration of steam with the formation of hydrogen by reaction, and this may be increased by the diffusion of hydrogen from the kiln gases until reducing conditions are obtained. It is desirable, therefore, to get rid of all water-vapor at the lowest temperature possible. The dashed line in Fig. 1 gives the equilibrium for CO–CO_2 and iron oxides and indicates, by the same reasoning, that if CO_2 is present in the ware it should be there in a high concentration.

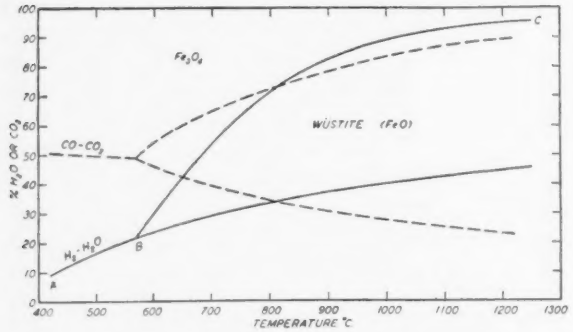

FIG. 1.—Equilibrium data for the systems Fe–H_2–H_2O (solid line) and Fe–CO–CO_2 (dashed line), based on the work of Emmett and Schultz. (*Jour. Amer. Chem. Soc.*, **55**, 1376 (1933)).

The control of these reactions is important because carbonaceous matter and iron compounds, either individually or together, lead to the formation of "black cores." This is often due to a deficiency of oxygen by reason of which organic matter is incompletely oxidized and the iron remains in the ferrous condition forming ultimately a fusible ferrous silicate which results in a low-temperature vitrification in the interior of the ware. It is evident, therefore, that, aside from the question of combustion, the atmosphere in the kiln should be carefully regulated so as to maintain proper excess of oxygen in the ware.

The rate of decomposition of carbonates and sulfides also becomes important in this range. For example, ferrous carbonate dissociates at about 500°C, while the sulfide in the presence of air commences to oxidize below 500°C and is fully converted to hematite and magnetite at 1000°C.

V. Vitrification Period

The climax of the firing process is the so-called vitrification period, for it is then that the important reactions which determine the strength, refractoriness, and similar properties of the finished ware occur.

VI. Formation of a Liquid Phase

The most important of these reactions is the formation of a liquid phase, which may vary from a small amount of melting to form a vitreous bond, as in a silica brick, to almost a complete fusion in the case of the finest grades of porcelain. In this case both the state of equilibrium and the rate of approach to it are important. A knowledge of the former can be gained from the phase diagram of the system in question, for such a diagram is in effect nothing more than a convenient way of compiling the data on the influence of temperature and composition on the equilibrium. For each composition there is a minimum temperature below which fusion can not take place; there is another temperature at which, given sufficient time, complete liquefaction will occur, and at any temperature in between these two there is a definite proportion of liquid which may be formed. All this information is given on a phase diagram such as that in

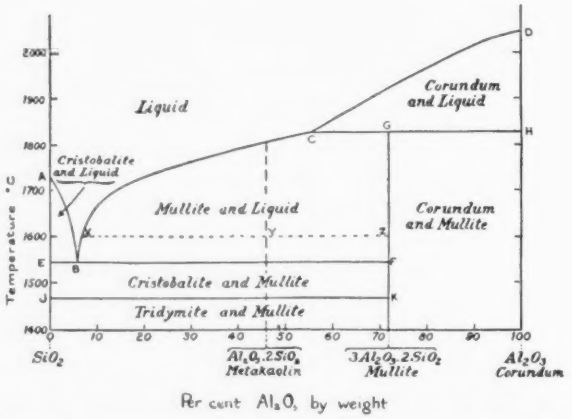

FIG. 2.—Equilibrium diagram for the system Al_2O_3–SiO_2 as given by Bowen and Greig (line for "metakaolin" added).

Fig. 2[1] for the system Al_2O_3–SiO_2. To take a simple example, a pure kaolin will have on dehydration about the composition given by the line shown for metakaolin, a term used here only for convenience of discussion without implying anything as to the physical constitution of the clay. The diagram indicates in this case that no liquid can be produced below 1549°C and that melting is not complete until approximately 1800°C. Metakaolin does not have a true melting point, however, but decomposes into phases which have the composition represented by the boundaries of the phase field at 1549°; that is, the liquid formed has the eutectic composition (*B*), while the solid remaining tends to be converted into mullite. The limiting proportion of liquid which can be produced at any temperature is given by the relative lengths of horizontal lines drawn from the vertical one representing the composition to the boundaries of the phase field. Thus in the case considered, the maximum proportion of liquid which can be produced at 1600° is given by the ratio of the length, *YZ*, to the whole length, *XZ;* the proportion of solid present is then the ratio *XY* to *XZ*.

Such diagrams, while of great usefulness in establishing the limits within which we can operate, give no indication of the rate of the process concerned, in this case the rate of melting. This is an important qualification because the silicates represent the rare case in which the rate of melting is slow, and therefore considerable time must usually be allowed for equilibrium to be established. Obviously fusion can not go on faster than the latent heat of fusion can be supplied, but in most practical cases this effect is negligible compared to the rate of melting, which is the limiting factor. To take an extreme example, the rate of melting of quartz is so slow that it may be equalled or even exceeded by the rate of crystallization of the resulting glass to cristobalite, a circumstance which has made it difficult to determine the true melting point of quartz.

The formation of a liquid phase is occasionally also a preliminary step in the formation of a new compound or of another modification which crystallizes then or later on cooling. This will be discussed in more detail in the following section.

[1] Taken from N. L. Bowen and J. W. Greig, "The System Al_2O_3–SiO_2," *Jour. Amer. Ceram. Soc.*, **7** [4] 238–54 (1924); *errata, ibid.*, **7** [5] 410 (1924.)

VII. Formation of a New Crystalline Compound

The equilibrium conditions for the reaction of two or more substances to form a new compound can be obtained qualitatively from the equilibrium diagram or, if the prerequisite thermodynamic data are available, can be calculated. Very few such data of sufficient accuracy are available at present, but the next few years should bring a considerable advance along this line of attack. Meanwhile, the equilibrium diagrams suffice for most purposes. For example, one of the most interesting and important sets of changes from a ceramic point of view is that taking place on heating clay. Much speculation as well as study has centered around the course of these reactions but no convincing conclusions have as yet been reached. I do not wish to enter this controversial field except to point out that the diagram tells us what the final products are; and it seems now to be generally accepted that kaolin and its dissociation products change to mullite and cristobalite as the temperature approaches that of the eutectic in this system (1549°C). Another case of compound formation in which rate of reaction is significant is the combination of magnesia and silica to form forsterite. The equilibrium conditions favor the formation of forsterite so that in this case the success of the process depends primarily on raising the temperature to a point at which the reaction goes on at an economically feasible rate.

In discussing rates we must not lose sight of the other factors involved, namely, the presence of a flux and the grain size. Fluxes usually act in one of two ways: they react to form fusible silicates, or they melt themselves. In either case, the liquids formed at a low temperature dissolve other constituents, thereby permitting reacting substances to come into contact more easily and so hasten the reaction. The grain size also has an influence, for the greater the surface, the greater the zone of interaction; that is, other things being equal, the finer the grain, the faster the reaction.

VIII. Crystal Transformation

Transformation reactions are of importance chiefly in highly siliceous materials but occur in most ceramic ware. They are interesting in that they provide a clear-cut case of the necessity of taking into account both equilibrium and rate of

reaction. The stability range of each of the modifications of silica is now known with considerable accuracy; quartz is stable up to 870°C, tridymite is stable between 870°C and 1470°C, and cristobalite between 1470°C and its melting point, 1728°C. It is, of course, possible by selecting an appropriate temperature and flux to cause any of the modifications to change to any other, but the equilibrium conditions place definite limits on what can be done in a given temperature range. Thus no amount of heating above 1470°C will cause cristobalite to change to quartz or tridymite. In this case the influence of composition on the equilibrium is not marked, however, because crystalline silica does not dissolve enough of other compounds to change its stability ranges appreciably.

The rate of transformation varies greatly under different circumstances, depending on the temperature, the presence of fluxes, and the size and condition of the grains. For example, in the transformation of quartz to cristobalite, no change is possible below 870°C. Between 870° and 1470° the reaction proceeds as a preliminary step in the formation of tridymite, which is the stable form in this range; while above 1470° the transformation is direct. The rate of transformation becomes appreciable at about 1000°C and increases rapidly with increasing temperature until at 1600°C one hour usually suffices for complete conversion even in the pure material. The state of subdivision and the degree of twinning of the quartz also have a considerable effect. According to Sosman,[2] a large homogeneous untwinned crystal transforms extremely slowly, but without a change of temperature the same quartz may be made to change much more rapidly by reducing it to a fine powder. Finely twinned vein quartz, even though in large fragments, transforms more rapidly than a finely powdered untwinned crystal, while powdering this twinned quartz produces an increase in rate even above that characteristic of the large twinned fragments. The formation of cristobalite in the fusion of quartz has already been mentioned. An extreme case of the effect of a flux is found in the transformation of cristobalite to tridymite at 830°; in the presence of sodium tungstate, cristobalite can be converted to tridymite in a few hours, whereas in the pure state over 3 months' heating at this temperature is required to produce a detectable amount of conversion.

[2] R. B. Sosman, The Properties of Silica, p. 67. Chemical Catalog Co., New York, 1927.

IX. Sintering and Grain Growth

The sintering and growth of the grains in the ware is a change which, though not always desired, often happens. Sintering is a general phenomenon which may be produced by several causes. It may arise from the incipient melting of fine particles whose melting point is lowered by the greater surface energy, it may be due to a fluxing action of impurities which tend to concentrate on the surface of the grains, it may sometimes be considered as a diffusion of the substance within itself so as to heal cracks and repair imperfections in the crystal lattice, or it may be a special case of grain growth since, in general, big grains tend to form at the expense of little ones because of their lower surface energy. In any case the rate of sintering or grain growth is a specific property varying greatly with the material.

X. Reactions on Cooling

(1) Crystallization from a Liquid Phase

One of the most important changes on cooling is the crystallization of any liquid phase present in the ware. In some cases, the same material that melted reappears; in others, a new compound forms, as in the alumina–silica system shown, in which mullite appears when fused kaolin cools. In reactions of this type, the rate of cooling may have a profound influence on the result because the rate of crystallization of many liquid silicates is very slow indeed.

(2) Annealing of a Vitreous Phase

In many instances it is desired to retain the glassy phase and, in such cases, a relatively rapid rate of cooling can be used. If a large proportion of glass is retained, however, the cooling schedule of the ware should be adjusted to give the glass present a proper anneal. Considering the care taken by glassmakers to anneal their product, it is impossible to escape the suspicion that the cooling of clayware deserves much more attention than is commonly given to it. The question of proper annealing has been discussed at some length by Williamson and Adams[3] in their classic

[3] Williamson and Adams, *Jour. Franklin Inst.*, **190**, 597–631, 835–70 (1920).

papers on the annealing of optical glass in which they showed that if the glass is held at constant temperature in the annealing range (slightly above 500°C) until strain is removed, or reduced to a very low value, the glass can be cooled at a relatively rapid rate without impairing its quality. I suggest that a similar treatment for certain types of ceramic ware might offer some advantages.

(3) Crystal Inversions

The only inversion which is likely to cause trouble on cooling is the cristobalite inversion at about 250°C, which is accompanied by a large and relatively sudden change of volume. Damage from this cause should, however, not be serious except in highly siliceous materials which have been converted to cristobalite.

(4) Temperature Distribution within the Ware

Thus far only the chemical aspect of the firing process has been considered in detail. The other aspect, the physical one, is concerned chiefly with the problem of how to get heat and temperature into the ware without introducing a large thermal gradient.

The desirability of having uniform temperature within each piece being heated has already been touched upon in connection with the removal of water, but it becomes even more evident when one considers the stresses which may be set up by a temperature gradient. Thus, there is the stress arising from reversible thermal expansion; for if the outer layers of the ware are at a different temperature from the interior, they expand differently and tend to pull away, causing stresses which may become very large as the temperature difference increases. An additional stress is also introduced by the differential change of volume resulting from the several reactions already discussed. In most cases the hotter part of the ware tends to shrink, but in a few cases, notably in silica brick, there is an expansion due to the transformation of quartz to tridymite and cristobalite. In a material of relatively high ductility, such as a metal, these stresses are relieved by plastic deformation, but in ceramic ware, which is relatively brittle, they frequently lead to surface cracking or spalling.

The problem in this case is not the usual one of finding the quantity of heat flowing through a body under a given temperature gradient after the steady state has been established, but is rather that of determining the rate of conduction, or diffusion, of temperature under nonequilibrium conditions. The mathematics applicable to this problem is the same as that for any case of diffusion; and the general equation for three-dimensional flow of temperature is

$$\frac{\partial\theta}{\partial t} = \kappa\left(\frac{\partial^2\theta}{\partial x^2} + \frac{\partial^2\theta}{\partial y^2} + \frac{\partial^2\theta}{\partial z^2}\right). \qquad (1)$$

Where θ = the temperature
t = the time
x, y, and z = coördinates
κ = a quantity called the thermal diffusivity or thermometric conductivity.

The last is a proportionality factor entirely analogous to thermal conductivity in the equation for the steady state, and is numerically equal to the thermal conductivity divided by the specific heat per unit volume.

The problem becomes, then, one of finding a solution of equation (1) which fits a particular set of practical conditions. A number of such solutions have been worked out for different conditions of temperature rise at the surface but we shall consider only one, namely, a constant rate of increase or decrease; for many firing schedules give a fair approximation to this condition. Equations for this case as applied to several simple geometrical shapes are given by Williamson and Adams[4] and we shall apply their results to the practical case of a standard size brick, (1) because it is one of the thickest shapes and the temperature lag is appreciable and (2) because it has a simple and regular form.

Neglecting the first few hours of heating, their equation for the rise of temperature at the center of a brick when the surface is heated at a rate of h degrees per hour, can, by methods given in detail in the Appendix, be reduced to the following:

$$\theta_c = ht - 1.5h/\kappa \qquad (2)$$

Where θ_c = temperature at center
t = elapsed time of heating in hours
κ = diffusivity. The first term on the right-hand side, ht, gives the temperature of the surface, hence the temperature at the center lags behind that at the surface by an amount given by $1.5h/\kappa$.

Taking the diffusivity, κ, of fireclay brick as 1.7 in.^{2}/hr., which is a good average value, we find that the center of such a brick lags behind the surface by approximately $0.9h$, so that if the rate of heating is 20°C/hr., the center will be only 18°C behind the surface. For a silica brick the diffusivity is somewhat greater, being about 2.5 in.^{2}/hr.;

[4] Williamson and Adams, *Phys. Rev.*, **14**, 99 (1919).

hence the lag in silica is only $0.6h$, and at a rate of 20°C/hr., the center is only 12°C behind.

Obviously for a thinner form the lag will be very much less; for example, using the dimensions of a split, we get as an approximate relation $\theta_c = ht - 0.5h/\kappa$; and for fire clay the lag at the center is $0.3h$, which is very small indeed. It appears, therefore, that, if the surface is heated uniformly at a reasonably slow rate, large temperature gradients are not likely to exist, provided, of course, that no reaction accompanied by a heat effect is taking place.

On the other hand, if a heat of evaporation or of melting or of reaction enters, the apparent volume specific heat is considerably increased and the diffusivity will fall, bringing about larger gradients. A good example of this is given by Theobald and Green[5] who measured the surface and

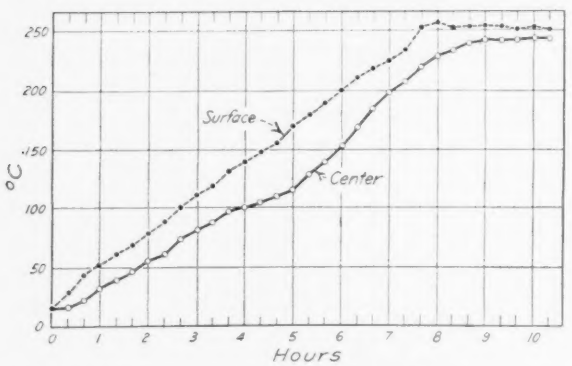

FIG. 3.—Time-temperature curves for the surface and center of a standard size fireclay brick heated uniformly at a rate of 30°C per hour (after Green and Theobald).

center temperature of a fireclay brick in the water-smoking period for different rates of heating. Their results for a rate of 30°C/hr. (55°F/hr.) are given in Fig. 3 and clearly show the increased lag due to the evaporation of water. The same brick when heated at 10°C/hr. gave very little indication of the arrest at the center. The same effect is, of course, characteristic of melting or any other change in which heat is absorbed.

By changing the sign, h (the rate of heating), all the equations given can be applied to cooling, and the conclusions derived for heating are valid if the term "cooling" is substituted for "heating." They indicate that on uniform cooling of the surface at a slow rate no appreciable thermal gradients are likely to exist unless some reaction which evolves heat, such as crystallization, takes place. In this case a lag entirely analogous to that resulting from melting on heating is introduced. This fact emphasizes again that in many cases a proper schedule on cooling may be nearly as important as in heating.

XI. Conclusion

From the foregoing discussion it would appear that close control of temperature, of rate of rise of temperature, and of the composition of the furnace gases is desirable. In the water-smoking period the optimum conditions, insofar as the changes taking place in the ware are concerned, are (1) rapid removal of water-vapor, (2) uniform rate of heating, and (3) uniform temperature distribution both within the ware and throughout the kiln.

In the oxidation period an excess of oxygen in the furnace gases is necessary to maintain an oxidizing atmosphere within the ware itself. In the vitrification period heating should be slow enough to permit reactions or physical changes, such as melting, which absorb heat and are inherently sluggish in silicate systems, to go on to the desired end. And in cooling, the rate of decrease of temperature should be adjusted so as to give a proper annealing treatment to the vitreous phases in the ware.

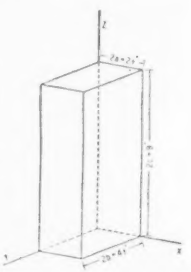

FIG. 4.—Position of standard size brick in the coördinate system.

Uniform heating or cooling of the surface of the ware at a relatively slow rate, about 15°C/hr. or less, insures freedom from thermal gradients, even when reactions with a heat effect occur. Obviously if the temperature of the surface is not raised uniformly large gradients may exist. It is desirable, therefore, that heating of the surface of the ware be as uniform as possible and that the temperature of the kiln be as uniform as possible. But the means of accomplishing these ends is a question of furnace design and operation and is beyond the province of this paper.

APPENDIX

For a standard-sized brick placed in a coördinate system as shown in Fig. 4, the equation given by Williamson and Adams[6] for computing the temperature, θ, at any point

[5] L. S. Theobald and A. T. Green, "The Temperature Gradients Obtained by Different Rates of Heating in Unfired Fireclay Brick between 15°C and 250°C," *Trans. Ceram Soc.* [Eng.], **24,** 105 (1924–25).

[6] Williamson and Adams, *loc. cit.*

in the brick when the surface is uniformly heated at a constant rate of $h°$ per hour is

$$\theta = ht - \frac{8h}{\kappa} \sum \frac{\sin \frac{Q_m x}{a} \sin \frac{Q_n y}{b} \sin \frac{Q_p z}{c}}{Q_m\, Q_n\, Q_p \left[\frac{Q_m^2}{a^2} + \frac{Q_n^2}{b^2} + \frac{Q_p^2}{c^2}\right]} \left[1 - e^{-kt\left\{\frac{Q_m^2}{a^2} + \frac{Q_n^2}{b^2} + \frac{Q_p^2}{c^2}\right\}}\right] \quad (3)$$

Where t = elapsed time in hours since start of heating
a, b, c = half dimensions of the brick (in this case, $1^1/_4$, $2^1/_4$, and $4^1/_2$ in., respectively)
κ = the diffusivity in in.^{2} per hour
$Q_m, Q_n, Q_p = \frac{(2m-1)\pi}{2}, \frac{(2n-1)\pi}{2}$, and $\frac{(2p-1)\pi}{2}$, respectively, in which m, n, and p are all positive integers.

This equation as it stands is a rather complex one but can be simplified by making a few assumptions. Thus, inspection shows that time, t, enters only in the term giving the surface temperature (ht) and in the exponential term. As t increases, the exponential becomes smaller and, in considering most ceramic ware, becomes negligible after about 2 hours, hence this term may be dropped without introducing an error, giving

$$\theta = ht - \frac{8h}{\kappa} \sum \frac{\sin Q_m x/a \sin Q_n y/b \sin Q_p z/c}{Q_m, Q_n, Q_p \left[\frac{Q_m^2}{a^2} + \frac{Q_n^2}{b^2} + \frac{Q_p^2}{c^2}\right]} \quad 4$$

which indicates that after a short time the temperature at any point in the brick increases at the same constant rate as the surface temperature but that it lags behind the surface temperature by an amount given by the summation term.

Moreover, we are interested primarily in the penetration of temperature to the center of the brick, and for this case the sine terms become unity, giving

$$\theta_c = ht - \frac{8h}{\kappa} \sum \frac{1}{Q_m, Q_n, Q_p \left[\frac{Q_m^2}{a^2} + \frac{Q_n^2}{b^2} + \frac{Q_p^2}{c^2}\right]} \quad (5)$$

Fortunately, for the values of a, b, and c corresponding to a standard brick the series is rapidly convergent; hence putting in numerical values and carrying out the summation, we get

$$\theta_c = ht - 1.5h/\kappa \quad (6)$$

or for a split

$$\theta_c = ht - 0.5h/\kappa \quad (7)$$

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THE CHEMICAL DURABILITY OF GLASS*

A Plea for a Standard Method of Test

BY W. E. S. TURNER

ABSTRACT

The chemical durability of glass is measured by a very wide variety of empirical methods, and the need is urgent for a common method by which scientific workers can obtain results under comparable conditions. The defects of methods employing surfaces of manufactured articles on the one hand and glass grains on the other are recognized and discussed, and the view is expressed that, in our present state of knowledge, the use of glass in the form of grains of controlled size offers the fewer objections. Two well-known methods of testing glass grains, namely, the Sheffield method and that of the Deutsche Glastechnische Gesellschaft, are discussed. International coöperation in establishing a common method is invited.

I. Introduction

The importance of the subject of the durability of glass began to be recognized as soon as chemistry began to assume a quantitative basis. Lavoisier,[1] for example, showed that earthy matter in glass vessels in which water had been boiled for prolonged periods was not due to the conversion of water into earth but to the extraction of matter from the glass. During the 19th Century, outstanding chemists who devoted themselves to the precise determination of atomic weights (J. J. Berzelius, J. B. Dumas, and J. Stas[2]) became increasingly aware of the problem; ultimately Stas devoted some years at the middle of the 19th Century to experimental work on new glasses suitable for chemical purposes. As time has passed, the importance of chemical durability has been increasingly recognized in connection with every type of glass: optical glasses, light-blown scientific apparatus, sheet glass, hollow

* Presented at the Summer Meeting, Glass Division, American Ceramic Society, September 14, 1934. Revised paper received December 26, 1934.

[1] A. L. Lavoisier, Mémoires de l'Academie des Sciences, pp. 73 and 90 (1770).

[2] J. Stas, *Chem. News*, **17**, 1 (1868).

domestic glassware, and bottle glasses. The user of glass containers, to an ever-increasing degree within the past decade, has been insisting on the supply of glassware which, under specified conditions, yields not more than a certain maximum of alkali to the contents. The determination of the corrosion of glass has, accordingly, attracted many investigators and there is no other subject in glass technology which has so extensive a literature.

NOTE: An up-to-date bibliography of the subject would contain references to about 200 papers. From the Department of Glass Technology alone, since 1917, 25 papers on the general subject and several others containing records of tests on new glasses have been published.

Despite this great and general activity on the part of workers in several countries, no one recognized method of testing the chemical durability has yet been generally accepted.[3] It has seemed as if nearly every new worker in the field has wished to add still another method of experimental determination. It is true that from the many and various methods certain generally recognized facts relating to the connection between chemical composition and chemical durability have emerged; but whereas careful workers can make determinations of physical properties such as density, refractive index, thermal expansion, and even viscosity at high temperature with such degree of accuracy that comparisons of results obtained by different investigators can be readily instituted, this is not the position in regard to glass corrosion; until this is possible, satisfactory scientific progress can not be made. Indeed, it is a reproach to glass technology that general agreement on a standard method, even if it be known to be imperfect, should not as yet have been achieved.

II. Methods of Testing the Durability of Glass

Those investigators who have spent much time in testing the chemical durability of glasses know well that however simple the determination of this property may be it has many pitfalls. I can recall a war-time Committee of eminent chemists in England engaged in testing, by a common method we thought clearly defined, the corrosion of chemical glassware and being perplexed that our results did not always agree at all closely. In recent years in the Glass Standards Committee of the Society of Glass Technology we had a striking object lesson of the need of meticulous care in defining the conditions of test and of carrying out the test in connection with the determination of the chemical durability of glass bottles. The test had reference to 4-ounce flat prescription bottles. After a considerable amount of preliminary work, the description of a test was drawn up and persons of wide experience and good standing in some half dozen laboratories were invited to coöperate by carrying out the test under precisely the same conditions, at approximately the same time, using samples drawn from a common stock of bottles made and sorted so that each investigator would have a series as nearly equivalent as possible.

The test in itself seemed simple enough in that it involved filling the bottle with distilled water and maintaining it at a carefully controlled temperature (the boiling point of water) for six hours, followed by subsequent titration. We anticipated quite close agreement; certainly we did not expect divergences of more than about 10%. Actually the results of different investigators differed by as much as 60% and it required several additional months of patient test and further comparison before we felt safe in drawing up the final conditions for a standard test.

The methods of testing chemical durability, as already mentioned, are exceedingly numerous. In general, the methods may be divided into two groups, (1) those in which the surface is tested either in the form of special test pieces (slabs, plates, rod, etc.) or in the form of hollow vessels, such as chemical glassware, bottles, etc., and (2) glass in the form of powder.

The tests, especially where water alone is concerned, may be carried out at a variety of temperatures not exceeding the boiling point (18°C, 80°C, and 100°C have all been utilized by different investigators), or the test may be carried out in an autoclave under pressure.

I am concerned in this paper with the question of a test suitable for glass as glass and not necessarily in the form of test pieces or vessels.

After long experience and consideration, I have been driven to the conclusion that, whatever

[3] One must bear in mind, of course, that the iodo-eosin test of F. Mylius and his classification of glasses according to their durability based on the test (*Sprechsaal*, **36**, 884, 924 (1903); *ibid.*, **43**, 594 (1910); *Silikat.-Z.*, **1**, 2, 25, 45 (1913)) have had considerable vogue, especially in the testing of optical glass.

imperfections and difficulties still lie in the use of the powder method, it is nevertheless, for the purpose of testing glass as glass, to be relied on and to be preferred to the use of glass made up into vessels.

My own approach to this conclusion was slow, but in 1922,[4] after five or six years devoted to the subject of testing chemical corrosion, I felt that the powder method was open to fewer objections than the method of testing the surface of vessels. My views on this point have been strengthened in the twelve years which have followed. The chief advantages of the powder method are as follows: (1) the amount of attack is greatly increased by reason of the enormously increased surface of the glass, so that the time required for a test can be reduced; and (2) glass in the form of powder reduces to a minimum the influences due to surface conditions, waviness, cordiness, or other general imperfections. In brief the powder represents a more homogeneous condition of the glass as glass.

The difficulties when glass is used in the form of vessels are indicated in part by the two advantages claimed for the use of powdered glass. A little more may be said, however, about the effect of surface. It is perfectly true that the manufacturer and the customer are concerned with the durability of the surface of the vessel. I am not arguing that durability determinations should not be made on glass vessels; but even with the same glass composition, the durability of glass surfaces when made up into vessels can be made to differ considerably according to the methods of manufacture and especially according to the methods of annealing adopted. As I am concerned in this paper, however, with a test which shall establish a chemical durability figure for glass as glass, a method should be employed free from those factors which especially influence the surface.

During the past few years further light has been thrown on this surface effect. Our own tests over several years have shown that the chemical durability figure differs, for glass containers in particular, depending on whether the container has been annealed in a closed or muffle leer or in contact with the products of combustion. The discovery or rediscovery of this fact has led some firms to go so far as to burn sulfur within muffle leers in order to improve the durability of the surface. Such treatment improves both the chemical durability and the mechanical strength.

We have also found that occasionally glass containers drawn from the leer at the same time may, when annealed in contact with the products of combustion, give strikingly different chemical durability figures, as derived from the alkali extracted by water. We have found differences of 100% between individual bottles taken from different positions in the leer, especially in the case of narrow-mouthed ware moving on a belt at a fairly high speed. The different durability figures doubtless arise from the uneven distribution of the leer gases which enter some of the containers more readily than others.

Other workers, for example, G. Keppeler, have directed attention to the fact that sheet glass annealed in a perfectly closed Fourcault annealing chamber has a surface durability poorer than that of corresponding glass annealed in the presence of products of combustion.

Although I have stressed certain advantages of the powder method and certain difficulties associated with the testing of the surface of glass vessels, I would like to add finally that the glass powder test in general does serve as a criterion of the durability of vessels into which the glass may be manufactured. This may be regarded as conclusively proved in the examples that follow.

(1) Peddle[5] showed that the powder test, which he used extensively, gave precisely the same order of classification in the case of five types of optical glasses derived from Schott as did Schott's original classification (based on the Mylius method) and also as did Peddle's special test of exposing the optically prepared surfaces of these same glasses to the ordinary atmosphere for a period of twelve months and determining the degree of tarnish produced.

(2) In the Department of Glass Technology we have utilized our own powder method extensively in testing the durability of various types of glassware, and in 1926 suggested limits of chemical durability on the basis of this test for satisfactory types of chemical glassware,

[4] W. E. S. Turner, "A Critical Examination of Methods Commonly Used in Determining the Durability of Glass," *Jour. Soc. Glass Tech. (Trans.)*, **6**, 30 (1922).

[5] C. J. Peddle, "Development of Various Types of Glass, II. Interaction of Silica, Lime, and Sodium Oxide," *ibid.*, **4**, 39 (1920).

glass tubing, and glass containers.[6] Recently, on the basis of the Deutsche Glastechnische Gesellschaft (D.G.G.) powder method, R. Schmidt and F. Späte[7] have drawn up a fairly elaborate scheme for testing glassware and have indicated the limits required for the classification of glasses employed for various types of manufactured articles.

III. The Glass Powder Test

Actually the use of glass powder for testing glass goes back many years. Faraday, in 1830, carried out some tests on the action of water on powdered glass. Variations on the method have been used from time to time but the two which in recent years have been very extensively used are (1) the method devised by myself in 1922[8] and subsequently used in numerous systematic researches in the past twelve years,[9] and (2) the method devised in the laboratories of the Osram G.m.b.H., tested extensively by Enss[10] and still further by Rexer,[11] and subsequently adopted by the D.G.G. as a standard method.

The conditions of test in these two methods are set out in the following table.

TABLE I

Conditions of test	Sheffield method	D.G.G. method
Powder size (grain diameter)	0.42–0.635 mm.	0.30–0.49 mm.
Containing vesse	Gauze cylinder, platinum or stainless steel (90-mesh/in.)	Loose in conical flask
Volume of water per gram of powder	Approx. 50 cc.*	Approx. 10 cc.
Temperature	Boiling water temperature	$CaCl_2$ bath at about 108°C
Time of boiling	1 hr.	5 hr.
Determination of corrosion	(*a*) Loss in weight (*b*) Titration of alkaline extract	Weight of residue after filtration and evaporation to dryness at 150°C

* Since the amount of corrosion is proportionate to the surface exposed, and since this will be proportionate to the density of the glass, a standard volume of powder and not a standard weight, is actually employed. The volume is that which corresponds to the weight of 10 grams in the case of a glass of specific gravity 2.5.

In both methods the preparation of the glass powder requires some care and all particles lying outside the diameter limits must be removed. This is specially important in the case of the finer particles. In practice, however, these difficulties have been overcome. The objection which has been raised to a powder method, namely, that different kinds of glass may give rise to very different shapes of grain, has not in practice been found to be of great weight. We do not find great differences in the form of the different grains.

IV. Reproducibility of Results by Powder Method

The general concordance between the powder method and the tests on the surface of manufactured glass have been referred to in a preceding section. It will be of interest to indicate how each of the two methods which have specifically been described lead (in the hands of careful workers) to quite satisfactory results.

TABLE II

REPRODUCIBILITY OF RESULTS BY THE SHEFFIELD METHOD

Type of glass	Reagent used (boiling)	Initials of investigator	Loss in weight (%)	Na_2O by titration (%)
Bottle glass (1)	Water	(M)	(1) 0.074 (2) 0.078	(1) 0.024
		(D)	(3) 0.068	(3) 0.022
Bottle glass (2)	Water	(J)	(1) 0.097	(1) 0.026
		(W)	(2) 0.09	(2) 0.03
Bottle glass (3)	Water	(SW)	(1) 0.068 (2) 0.072	
		(D)	(3) 0.066	
Tubing (1)	Water	(L)	(1) 0.017 (2) 0.020	
		(D)	(3) 0.015	
Tubing (2)	Water	(L)	(1) 0.024	
		(W)	(2) 0.026	
Tubing (3)	Water	(L)	(1) 0.012 (2) 0.012 (3) 0.011	
Na_2O–MnO–SiO_2 glass 832D*	2 *N* sodium carbonate	(W)	(1) 1.07†	
		(D)	(2) 1.09†	
Na_2O–MnO–SiO_2 glass 832G*	2 *N* sodium carbonate	(W)	(1) 0.85†	
		(D)	(2) 0.87†	

* For composition see A. A. Childs, V. Dimbleby, W. E. S. Turner, and F. Winks, *Jour. Soc. Glass Tech.* (*Trans.*), **15,** 172 (1931).
† These glasses were dried finally at 600° to obtain the true loss.

In Table II, sets of results obtained at various

TABLE III

COMPARISON OF THE SHEFFIELD AND THE D.G.G. METHODS
(Carried out in the Department of Glass Technology, Sheffield)

No. of determination	D.G.G. Method: Wt. of residue, dried at 150°C from solution (mg.) From 75 ml.	Calculated for 100 ml.	Wt. for 100 ml. corrected for blank	Sheffield Method: Loss in weight (%)	Na_2O extracted (%)
Blank	3.0	4.0			
Blank	2.8	3.73			
1	36.0	48.0	44.27	0.047	0.029
2	38.0	50.64	46.64	0.046	0.027
3	43.6	58.12	54.39	0.040	0.030
4	44.2	58.92	54.92		
5	42.0	57.0	52.27		
6	41.4	55.2	51.20		

[6] V. Dimbleby and W. E. S. Turner, "Relationship between Chemical Composition and Resistance of Glasses to the Action of Chemical Reagents, I," *Jour. Soc. Glass Tech.* (*Trans.*), **10,** 304 (1926).
[7] *Fachausschuss I Bericht,* No. 26 (1933). For a general discussion of the advantages of the powder method of test see F. Späte, *Glastech. Ber.*, **6,** 635 (1928–29).
[8] W. E. S. Turner, "A Critical Examination of Methods Commonly Used in Determining the Durability of Glass," *Jour. Soc. Glass Tech.* (*Trans.*), **6,** 30 (1922).
[9] V. Dimbleby and W. E. S. Turner, *loc. cit.*
[10] J. Enss, *Glastech. Ber.*, **5,** 449 (1927–28).
[11] E. Rexer, Dissertation, 1930; also *Keram. Rundschau,* **38,** 387 (1930).

times by different workers in the Department of Glass Technology are reproduced.

It will be seen that the degree of concordance after a worker has acquired the technique is reasonably good.

Next, it will be of interest to record some results which the Department of Glass Technology at Sheffield and the Osram laboratory in Berlin obtained, in which each laboratory operated both methods and in which the same glass was tested.

TABLE IV

COMPARISON OF THE SHEFFIELD AND D.G.G. METHODS
(Carried out in the Osram Laboratory, Berlin)

No. of determination	D.G.G. method Wt. of residue from 100 ml. solution (mg.)	Sheffield method Loss in weight (%)	Sheffield method Na_2O extracted (%)
1	49.1	0.038	0.032
2	50.9	0.049	0.031
3	49.3	0.053	0.033
4	52.8	0.054	0.033
5	53.6		
Av.	51.1	0.0485	0.032

TABLE V

FURTHER COMPARISON OF THE SHEFFIELD AND THE D.G.G. METHODS

(Carried out in the Osram Laboratory, Berlin, Using Three Different Types of Glass)

	D.G.G. method Residue from solution (mg.)		Sheffield method Loss in weight (%)		Sheffield method Na_2O extracted (%)	
Type of glass	First worker	Second worker	First worker	Second worker	First worker	Second worker
Molybdenum glass	8.8 8.1	8.5 8.3	0.008	0.015 0.019	0.00045 0.0002 0.0007	0.000 0.000
M glass (high PbO content)	11.8 10.9 10.0	8.8 8.7 9.2	0.014 0.014	0.024 0.029 0.022	0.013 0.0124 0.009 0.0118	0.0068 0.006 0.005
Ordinary hollow-ware glass	26.1 23.1 24.0	20.0 20.3	0.035 0.032 0.038 0.041	0.043 0.041	0.0142 0.0139 0.0127 0.0136	0.0163 0.0164

The results in general show that both methods lead to reasonably satisfactory results but that closer concordance is usually obtained in repeated determinations by workers following out their own method in which they have received special training. This is entirely a natural result.

V. A Common and Standard Glass Powder Test

If a majority of glass technologists in countries other than England and Germany can agree to adopt the powder method as a general standard method of testing the chemical durability of glass as glass, it remains to reconcile the various methods and views as to the details of such a test.

Kitaigorodsky[12] has independently carried out tests by the Sheffield method and the D.G.G. method and has indicated his preference for the Sheffield method. It may be that other independent workers would prefer the D.G.G. test.

For myself, I believe that both methods will give satisfactory results and that it ought to be possible, by compromise if necessary, to bring about an adjustment of methods, so that a common method can be adopted. I would like to urge strongly that this subject might be considered fully by a very small committee of the Glass Division selected from among those who have practical acquaintance with the subject. If the Committee finds it possible to recommend the adoption of the powder method as one on which a standard test should be based, the next question to be fixed will be this reconciliation between the varying views as to grain size, time of test, and method of determining the result. It should not be difficult for a small International Committee of unprejudiced glass technologists to bring about this common adjustment. When this has been done a test will be available; not necessarily a perfect test, but one which will enable investigators of the subject to derive results which will bear comparison, and, because comparison will be made possible, healthy criticism of the results will serve to bring to light additional information on matters which are now somewhat obscure.

Acknowledgment The author wishes to express his thanks to M. Thomas and J. Enss for their permission to incorporate the results summarized in Tables IV and V.

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[12] J. J. Kitaigorodsky and A. V. Polinkovskaya, *Trans. State Experiment Inst. Glass* [U. S. S. R.], No. 1 (1932).

PETROLOGY OF THE PENNSYLVANIAN SHALES AND NONCALCAREOUS UNDERCLAYS ASSOCIATED WITH ILLINOIS COALS. PART III (Conclusion)

By Ralph E. Grim

Including X-Ray Studies by P. F. Kerr and Chemical Studies by O. W. Rees

Editor's Note: Part I was published in the March *Bulletin*, pp. 113–19; Part II, in the April *Bulletin*, pp. 129–34.

Part III, the concluding installment covers sections IV (B), IV (C), V, and VI, concluding with Appendices I and II. The complete synopsis appears on page 113, the March *Bulletin*.

(B) Constitution of the Coarser Grade Sizes (Fraction B) of the Noncalcareous Underclays and Shales beneath the Coals

The examination of fraction B of the samples of shales underlying the coals shows it to have the same composition as fraction B of the shales above the coals.

The mineral components of fraction B of the noncalcareous underclays include quartz, pyrite, muscovite, chloritic material, feldspar, calcite, gypsum, zircon, tourmaline, rutile, biotite, epidote, staurolite, common hornblende, garnet, glauconite, anatase, brookite, and topaz. A few samples also contain clay mineral particles which have not been disaggregated.

(1) Quartz Quartz occurs in all samples, and usually makes up 90% or more of fraction B. Grains with a maximum diameter of 0.5 millimeter are present in a few samples, but their average size is usually 0.06 to 0.03 millimeter or less. The larger grains show a small degree of rounding, and the smaller ones are angular. Extinction shows no straining of the grains. Many of them contain an abundance of acicular inclusions.

(2) Pyrite Pyrite is abundant in some underclays, forming a larger percentage of fraction B than the quartz, whereas in others it is completely absent. It occurs in euhedral grains and in aggregates containing many euhedral grains ranging in size up to several millimeters in diameter.

(3) Muscovite Muscovite varies from rare to abundant in different samples. It occurs in flakes ranging in size up to 0.2 millimeter in diameter. The following optical data indicate that the mineral is muscovite: $\gamma = 1.595$; $\gamma - \alpha = 0.030$; $(-)$; $2V = 35°$. In several samples a few flakes with a slightly lower index of refraction and birefringence characteristic of the sericite-like mineral were found.

(4) Chloritic Material Chloritic material is rare to common. It is found as flakes and irregular micaceous particles with a maximum diameter of 0.15 millimeter. The mineral varies in color from light to dark green, and in its refractive index (γ) ranges from about 1.60 to 1.650.

(5) Feldspar Feldspar is rare or absent. It occurs in grains 0.06 millimeter or less in diameter which show little or no alteration. Albite and orthoclase were the only species that could be found.

(6) Calcite Calcite in small (0.06 to 0.02 mm.) irregular grains is common in a few samples.

(7) Other Minerals Other minerals in fraction B, including gypsum, zircon, tourmaline, rutile, biotite, epidote, staurolite, common hornblende, garnet, glauconite, anatase, brookite, and topaz, are all of minor importance, making up considerably less than 1 per cent of the total rock. These minerals are usually small (0.03 to 0.06 mm.) but occasionally have a diameter of 0.1 millimeter. Zircon and tourmaline in both well-rounded and angular grains are the most important. Other mineral grains are angular and exhibit little alteration.

Because of the rarity of the constituents of fraction B, except quartz and pyrite, caution must be used in generalizing on these data. It appears, however, that except for these two minerals, the mineral constituents of this fraction of the underclays are less abundant than in the corresponding fraction of the shales, although no significant differences in their identity or physical characteristics could be noted.

In the underclays themselves, there are significant variations in the relative abundance of the constituents of fraction B. Those underclays in which the essential constituent is kaolinite with little or no sericite-like mineral (Nos. 284, 271, and 206) contain an abundance of pyrite and very few other minerals. Feldspar, micas, and the so-called heavy minerals are absent or very rare in them. The other underclays (Nos. 207, 212, 48, 225, and 205) which contain appreciable sericite-like mineral possess much less pyrite but larger quantities of feldspars, micas, and heavy min-

erals. In other words, these latter underclays closely resemble the shales in the composition of fraction B whereas the former are somewhat different. Insufficient samples were studied to prove that all gradations between the two mineral assemblages can be found, but there is a definite suggestion that a gradation does occur.

An important reason for the identification of these minerals was the hope that those of detrital origin would yield evidence for the location of the source area. The small amount of "heavy mineral" data on possible source rocks has made it impossible to arrive at any satisfactory conclusions.

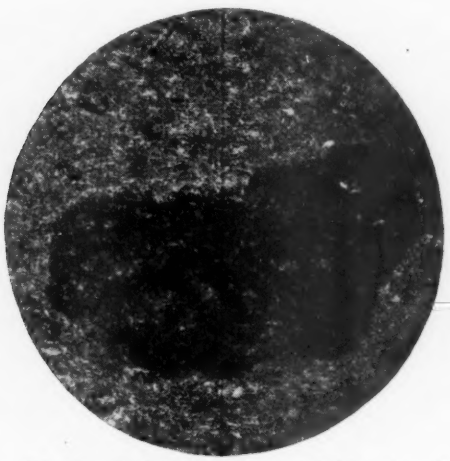

FIG. 5.—Pellet-shaped mass of clay mineral in the matrix. (Sample No. 274) Alton Brick Co., Alton. × 100.

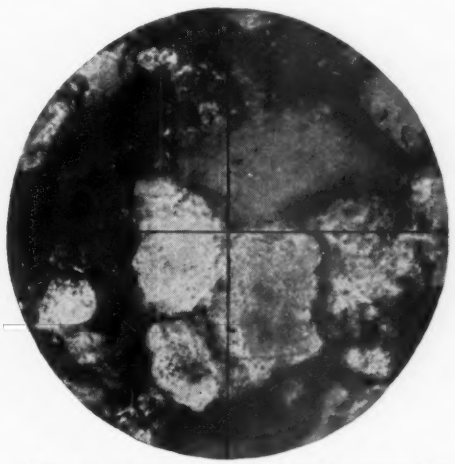

FIG. 6.—Quartz grains showing mutually accommodating boundaries indicating a post-depositional transfer of silica. (Sample No. 275) Alton Brick Co., Alton. × 100.

(C) Detailed Description of a Series of Noncalcareous Underclays

As the shales occurring beneath the coals are similar in every way to those occurring above the coal, a detailed description of them is not necessary. The following series of noncalcareous underclays illustrates the range of variation in composition, texture, etc., of the material studied:

(1) Alton Brick Co. Clay Mine Alton, Madison County. Sample from so-called Cheltenham clay directly beneath the Seahorne limestone of the lower Pottsville (sample No. 274). About 95% of this clay is composed of a light yellow-gray matrix which is composed of a mixture of particles of kaolinite, 0.001 millimeter or less in diameter, and flake-like particles of the sericite-like mineral with a maximum diameter of 0.005 millimeter. The degree of uniformity of orientation of the particles composing the matrix is variable. Where the sericite-like mineral is relatively abundant there is a high degree of uniformity of orientation; elsewhere it is small.

Pellet-shaped masses (Fig. 5) of the same material as the matrix are scattered through it. They vary in diameter up to several millimeters, and stand out from the matrix because of a lighter yellow color, a difference in size of constituent particles, or a variation in the relative abundance of component minerals. The boundaries of these masses are usually distinct, but occasionally they grade into the matrix.

The remainder of this clay is essentially quartz occurring in angular grains with a maximum diameter of 0.03 millimeter. They are scattered through the matrix or concentrated in small lenticular masses in which the individual grains show mutually accommodating boundaries.

A few distinct flakes of muscovite (0.06 millimeter maximum diameter) and occasional grains of pyrite are also present.

(2) W. S. Shaw Co. Pit Berdan, Greene County. This sample underlies coal No. 2 (sample No. 248). Approximately 60% of this clay is composed of a mixture of about equal amounts of kaolinite and the sericite-like mineral. The individual particles of the former are too small for size or shape determination whereas those of the latter mineral occasionally reach 0.02 millimeter and are flake-like in shape. This matrix is light gray-yellow in color and shows a fair degree of uniformity of orientation of the individual particles.

The remaining 40% of the clay is composed of unsorted, angular to rounded grains of quartz reaching a maximum diameter of 0.12 millimeter. The grains are scattered through the matrix or concentrated in streaks in which they often show mutually accommodating boundaries (Fig. 6). Certain of the quartz grains show evidence of partial replacement by the matrix material.

A few flakes of muscovite with a maximum diameter of 0.2 millimeter are either distinctly separated from the matrix or grade into it (Fig. 7).

(3) C. H. Myers Pit Colchester, McDonough County. This sample is from the underclay

of coal No. 2 (sample 245). This clay is composed of about 60% matrix and 40% quartz. The matrix is light gray-brown in color and is composed of a mixture of kaolinite and sericite-like mineral with the former constituent the more abundant. The sericite-like mineral occurs in flake-shaped particles reaching a diameter of 0.01 millimeter. Kaolinite is usually present in particles too small for size determinations, but occasionally occurs in poorly developed but characteristic vermicular grains (Fig. 8). The components of the matrix show no uniformity of orientation.

The quartz occurs in angular to slightly rounded, unsorted grains reaching 0.1 millimeter in diameter. They are scattered or concentrated in lenses. In the latter case, mutually accommodating boundaries are excellently shown by the individual grains.

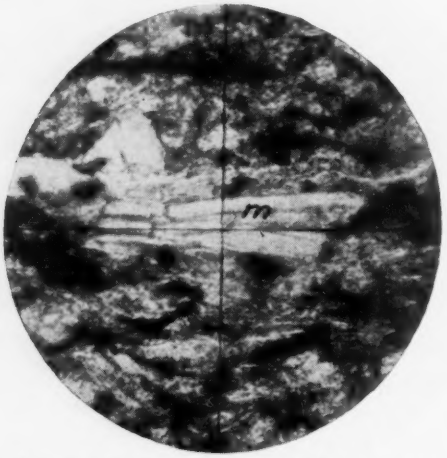

FIG. 7.—Book of muscovite (*m*) penetrated by matrix along cleavage surfaces. (Sample No. 248) W. S. Shaw Co., Berdan. × 200.

A few flakes of muscovite, reaching 0.25 millimeter in diameter and lacking any uniformity of orientation, are also present.

Localized elongate areas are stained red-brown by organic material.

(4) Chicago Retort and Firebrick Co. Pit Ottawa, La Salle County. Sample from the underclay below coal No. 2 (sample 206).

The matrix composing 75% of this clay is made up of kaolinite and a very minute quantity of the sericite-like mineral. With the exception of a few flakes of the latter mineral, 0.005 millimeter in diameter, the component particles are too small to permit determination of their size and shape. The matrix is light yellow-brown, probably resulting from a slight amount of organic material acting as a stain. No uniformity of orientation of the component particles is shown.

The remaining 25% of the rock is composed of grains of quartz varying in size up to 0.5 millimeter. The larger grains are well rounded. The large size of these quartz grains and their high degree of rounding is striking.

(5) Illinois Clay Products Co. Pit East of Morris, Grundy County. Sample from lower clay horizon directly underlying a Pottsville coal (sample No. 212).

This clay is made up of about 60% matrix and 40% quartz.

The matrix is red-brown in color due to the presence of organic material which adds to the difficulty of identifying the constituent minerals. It appears to be essentially composed of kaolinite in particles not large enough for size or shape determination, and a comparatively small quantity of flakes of the sericite-like mineral reaching a maximum diameter of 0.01 millimeter. The constituent particles of the matrix show a fair degree of uniformity of orientation. Some irregular portions of the matrix show a higher degree of uniformity of orientation and a darker red-brown color than the remainder. These areas are often slightly pleochroic, being darker parallel to *Z*. They grade into the remainder of the matrix and appear to differ in constitution from the other matrix material in containing a relatively larger proportion of the sericite-like mineral.

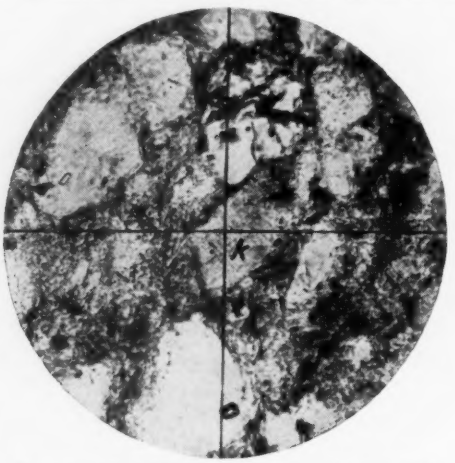

FIG. 8.—Poorly developed vermicular grain of kaolinite (*k*). (Sample No. 245) C. H. Myers Co., Colchester. × 100.

The quartz occurs in angular scattered grains with a maximum diameter of 0.06 millimeter.

V. Origin of the Shales and Underclays

It is generally recognized by all who have studied them that the shales overlying the coal beds are marine in origin. Weller[21] has recently summarized the evidence for this conclusion. The presence of glauconite in these shales is further evidence for this conclusion.

The shales beneath the coals, as well as the material of the underclays, have been considered to be of nonmarine origin by Weller.[21] The petrographic data yield no evidence for this conclusion and, except for the very rare grains of glauconite, they yield no important evidence against it. The extreme rareness of the glauconite and the pos-

[21] J. Marvin Weller, "Cyclical Sedimentation of the Pennsylvanian Period and Its Significance," *Jour. Geol.*, **38**, 97–135 (1930).

sibility that the grains may be detrital makes it unsafe to use its presence as definite evidence against a nonmarine origin for these beds. Further, it has been shown[22] that glauconite can form, in certain instances, after deposition in environments which are not marine.

The constant uniform mineral composition of fraction A of the shales is striking and has decided genetic implications. In every shale studied, fraction A is composed of the same sericite-like mineral and quartz. It is logical to postulate that the source area supplying these fine-grained sediments was widespread and underlain by a variety of rocks. The detrital minerals afford evidence that igneous and possibly metamorphic as well as sedimentary rocks were included in the source area. It would seem that the fine disintegration material yielded by such a widespread source-area and transported to the Pennsylvanian seas in this area would be mineralogically heterogeneous. A widespread source-area can, however, under some conditions supply uniform material to an evironment of deposition. Recent soil investigations have shown that soils with about the same composition in their finest grade sizes will develop in a widespread area under uniform climatic conditions, where sufficient time is available and where erosion is slow enough to permit the accumulation of the material developed by the soil-forming processes. It is believed that the uniformity of composition of these shales can not be satisfactorily explained in this manner. Shales reoccur many times in the Pennsylvanian section, and it is difficult or impossible to conceive that each time deposits yielding shales were formed, the source-area had reached the point where widespread soils with about the same composition in their finest grade sizes existed, and that only this soil material was being removed. It is more likely that such conditions in the source-area were not reached every time these sediments were deposited, that the fine material removed from the source-area was not limited to that obtained from the soils and, therefore, that the original debris of these shales was mineralogically heterogeneous. It should follow that the resulting sediments would be composed of a mixture of many minerals in their finest grade sizes. Since they are not heterogeneous, the inevitable conclusion is that the shales were not deposited with the present mineral composition of their finest grade sizes, but that these minerals developed from the original debris during or soon after deposition.

Attempts to unravel the history of the shales are complicated by the presence of muscovite and chloritic material whose characteristics indicate that they have formed after deposition from the sericite-like mineral. Hutchings,[23] and later Brammall,[24] have shown that there is a trend in the reconstitution in shales, slates, and phyllites toward the establishment of a metastable ternary system of white mica, chlorite (or chloritoid), and quartz. This is essentially a process of molecular differentiation starting imperfectly in the early stages of consolidation. The secondary muscovite and chlorite of the Pennsylvanian shales indicate, by their characteristics, a genetic history in agreement with this concept. In these shales the reconstitution is in a very early stage.

Several theories of the origin of the underclays have been given by various workers, but there is no general agreement as to their genetic history. Additional data on the calcareous underclays are required before their origin may be well understood. Studies aiming to obtain this information are in progress.

VI. Summary

In an investigation of the relation between the mineral composition and texture of Illinois clays and shales and the properties controlling their economic utilization, the first step was to obtain mineralogical and textural data for the materials to be studied. This has been done, and it is the purpose of this paper to present this information for the Pennsylvanian shales and clays together with certain conclusions that can be drawn from these data. The study of the control exerted by the mineral constituents and textures of these rocks on the properties determining their economic utilization is in progress and will be reported later.

It has been shown by means of optical, X-ray, chemical, and dehydration data that the shales occurring both above and below coals are essentially composed of a potash-bearing clay mineral closely resembling sericite. This clay min-

[22] L. Cayeux, "Contributions à l'étude micrographique des terrains sédimentaires," *Min. Soc. Géol. du Nord.*, **4**, 163–84 (1897).

[23] W. M. Hutchings, quoted by A. Brammall.

[24] A. Brammall, "Reconstitution Processes in Shales, Slates, and Phyllites," *Mineral Mag.*, **19**, 211–25 (1921).

eral, which in these shales has less K_2O and more H_2O than sericite, probably forms an isomorphous series with sericite. It has not been possible to obtain pure samples of this clay mineral; consequently its limits of composition can not be determined and it appears wise not to apply a specific name at this time. It is designated here as the sericite-like mineral. In addition to the sericite-like mineral, quartz is present in variable quantities occurring in grains varying in different samples from colloidal size to 0.1 millimeter in diameter. Muscovite and chloritic material are common constituents in almost all shales. Pyrite, biotite, calcite, and siderite are common in a few shales. Other constituents are very rare.

The uniformity of the composition of the fine-grade sizes of the shales both vertically and laterally is striking. In every shale the sericite-like mineral with small amounts of quartz forms these grade sizes. It is suggested that the constituents of the finest grade sizes of these rocks were not deposited with their present mineral composition, but that this mineral composition developed during and shortly after accumulation from the original debris which was probably heterogeneous mineralogically.

The optical, X-ray, chemical, and dehydration data all indicate that kaolinite, the sericite-like mineral, and quartz are the essential constituents of the noncalcareous underclays. Kaolinite is usually the dominant constituent. The relative abundance of the sericite-like mineral and quartz is not constant, so that the composition for different underclays varies from almost pure kaolinite to mixtures with a considerable quantity of the sericite-like mineral and quartz. In the latter case, the composition closely approximates that of the shales. Quartz and pyrite are also present in small variable quantities. Other mineral constituents are rare. The underclays which are nearly pure kaolinite contain appreciable pyrite, whereas feldspar, micas, and the so-called heavy minerals are absent or very rare. The underclays containing appreciable sericite-like mineral possess much less pyrite, but larger quantities of feldspar, micas, and heavy minerals.

The shales and clays investigated exhibit a wide variety of textures. Differences in texture are chiefly determined by differences in the relative abundance of the important constituent minerals, in the size of the constituents, and in the degree of uniformity of orientation of the clay mineral particles. This is illustrated excellently by laminated shales in which the lamination results from a succession of layers in which different layers possess different proportions of the constituent minerals, different degrees of uniformity of orientation of the clay mineral particles, or different sizes of constituents.

Appendix I

		Optical data for fraction A			
		γ	$\gamma - \alpha$	$2V$	Sign
	Greenbush shale, lower Pottsville				
213	Hydraulic Press Brick Co., Shale City, Mercer County	1.575	0.020	Small	(−)
234	Northwestern Clay Mfg. Co., Griffin, Mercer County	1.572	.025	"	"
267	Outcrop in creek bank, SW. 1/4 NW. 1/4 Sec. 12—T1W—R9S, Williamson County	1.580	.030	"	"
	Francis Creek shale overlying Coal No. 2				
204	Chicago Retort and Firebrick Co., Ottawa, LaSalle County	1.572	.025	"	"
288	Herrick Clay Mfg. Co., Ottawa, LaSalle County	1.570	.025	"	"
210	Mid-West Brick Co., Tonica, LaSalle County	1.563	.020	"	"
253	Midland Electric Coal Co., strip mine, Annawan, Henry County	1.570	.030	"	"
214	Outcrop in creek bank, SW. 1/4 NW. 1/4 Sec. 4—T5N—R3E, Fulton County	1.580	.025	"	"
249	Colchester Brick and Tile Co., Colchester, McDonough County	1.574	.022	"	"
242	White Hall Sewerpipe and Stoneware Co., White Hall, Greene County	1.574	.025	"	"
275	Alton Brick Co., Alton, Madison County	1.574	.025		

Appendix I (*continued*)

		Optical data for fraction A			
		γ	$\gamma - \alpha$	$2V$	Sign
	Purington shale overlying the Francis Creek shale and Coal No. 2				
36	Outcrop, center NW. 1/4 Sec. 32—T34N—R4E, LaSalle County	1.572	.025	Small	(−)
203	National Fireproofing Co., Twin City plant, LaSalle County	1.572	.022	"	"
244	Purington Paving Brick Co., Galesburg, Knox County	1.572	.022		
240	Same as 244, but lower in section exposed	1.572	.020		
247	Outcrop, creek bank, NW. 1/4 NW. 1/4 Sec. 33—T6N—R3E, Fulton County	1.572	.020	"	"
241	White Hall Sewerpipe and Stoneware Co., White Hall, Greene County	1.574	.025	"	"
235	Same as 241, but lower in section exposed	1.580	.025	"	"
273	Alton Brick Co., Alton, Madison County	1.576	.030	"	"
259	Outcrop in road cut, SW. 1/4 NE. 1/4 Sec. 14—T18N—R11W, Vermilion County	1.576	.030	"	"
	Canton shale overlying Coal No. 5				
219	Outcrop creek bank, SW. 1/4 Sec. 35—T13N—R4E, Knox County	1.580	.025		
215	Same as 219, but lower in section exposed	1.580	.025	"	"
217	Outcrop creek bank, SE. 1/4 Sec. 21—T6N—R3E, Fulton County	1.579	.027		"
222	Outcrop creek bank, NE. 1/4 SE. 1/4 Sec. 33—T7N—R4E, Fulton County	1.571	.022	"	"
233	Outcrop creek bank, NE. 1/4 Sec. 1—T7N—R4E, Fulton County	1.570	.025		"
223	Outcrop creek bank, NW. 1/4 Sec. 26—T2N—R1W, Schuyler County	1.572	.022	"	"
	Sheffield shale overlying Coal No. 6				
254	Sheffield Clay Products Co., Sheffield, Bureau County	1.574	.025	"	"
231	Same as 254, but higher in section exposed	1.572	.025		
272	Peabody Coal Co., strip mine, NE. of Duquoin, Perry County	1.572	.030	"	"
	Farmington shale overlying Coal No. 7				
202	Streator Clay Mfg. Co., Streator, Livingston County	1.572	.025	"	"
209	Streator Brick Co., Streator, LaSalle County	1.575	.025	"	"
227	Hydraulic Press Brick Co., Sparland, Marshall County	1.575	.025	"	"
221	Outcrop in creek bank, SE. 1/4 SE. 1/4 Sec. 14—T15N—R8E, Bureau County	1.574	.022	"	"
226	Outcrop in road cut NE. 1/4 Sec. 1—T7N—R4E, Fulton County	1.578	.028	"	"
251	Outcrop in creek bank, NW. 1/4 Sec. 26—T2N—R1W, Schuyler County	1.580	.025		"
239	Petersburg Brick and Tile Co., Petersburg, Menard County	1.575	.025	Medium	"
237	Same as 239, but lower in section exposed	1.579	.028	"	"
258	United Electric Coal Co., strip mine, Danville, Vermilion County	1.576	.025	Small	"
261	Danville Brick Co., Danville, Vermilion County	1.570	.020		
260	Same as 261, but lower in section exposed	1.570	.020		
285	Western Brick Co., Danville, Vermilion County	1.575	.025	"	"
	Trivoli shale overlying Coal No. 8				
243	Posten-Springfield Brick Co., Springfield, Sangamon County	1.576	.025	"	"
238	Same as 243, but lower in section exposed	1.580	.025		
270	Alton Brick Co., Edwardsville, Madison County	1.574	.025	"	"
282	Outcrop in road cut SE. 1/4 Sec. 5—T4S—R4W, Perry County	1.583	.025	"	"
	Shale directly above Collinsville limestone				
266	Hill Brick Co., pit near O'Fallon, St. Clair County	1.574	.025		"
280	Hydraulic Press Brick Co., Haydite plant, near O'Fallon, St. Clair County	1.575	.025	"	"
	Shale underlying the Collinsville limestone				
279	Same as 280	1.570	.020	"	"
	Shale overlying the Shoal Creek limestone				
229	Carlinville Tile Co., Carlinville, Macoupin County	1.575	.025	"	"
230	Outcrop in creek bank, NE. 1/4 NW. 1/4 Sec. 35—T10N—R7W, Macoupin County	1.570	.025		"
	Shales from the upper Pennsylvanian				
277	Richards Brick Co., pit New Douglass, Bond County	1.577	.025	"	"
281	Same as 277, but lower in section exposed	1.574	.025	"	"
262	Albion Brick Co., Plant No. 1, Albion, Edwards County	1.572	.030	"	"
264	Same as 262, but higher in section exposed	1.574	.025	"	"
276	Albion Brick Co., Plant No. 2, Albion, Edwards County	1.576	.025		
278	Same as 276, but lower in section exposed	1.575	.025	"	"
	Miscellaneous shales of Pennsylvanian age				
263	McLeansboro Shale Products Co., McLeansboro, Hamilton County. Macoupin shale	1.577	.025	"	"
265	Murphysboro Paving Brick Co., Murphysboro, Jackson County. Shale overlying first coal above Murphysboro coal	1.570	.025	"	"
269	Ford Brick and Tile Co., Harrisburg, Saline County. Shale overlying Harrisburg coal	1.570	.025		

Appendix II

		Optical data for fraction A			
		γ	$\gamma - \alpha$	$2V$	Sign
	Shales occurring beneath coals				
224	Peoria Brick and Tile Co., East Peoria, Tazewell County. Below coal No. 6	1.574	0.023		
252	Colchester Brick and Tile Co., Colchester, McDonough County. Below coal No. 2	1.570	.030	Small	(−)
268	Murphysboro Paving Brick Co., Murphysboro, Jackson County. Below first coal above the Murphysboro coal	1.573	.025	"	"
	Lower Pottsville underclays				
207	Illinois Clay Products Co., near Morris, Grundy County	1.562	.012	"	"
212	Same as 207, but lower horizon	1.567	.020	"	"
41	Argillo Clay Works, Carbon Cliff, Rock Island County	1.570	.022		
232	Northwestern Terra Cotta Co., Colchester, McDonough County	1.564	.018		
48	Outcrop near shaft of N.W. Terra Cotta Co., Colchester, McDonough County	1.567	.015	"	"
245	C. H. Myers clay pit, Colchester, McDonough County	1.565	.015	"	"
250	Colchester Brick and Tile Co., Colchester, McDonough County	1.566	.018	"	"
256	Frederick Brick and Tile Co., Frederick, Schuyler County	1.566	.020	"	"
257	Same as 256, but higher in section exposed	1.566	.020	"	"
228	J. V. Wyatt clay mine, White Hall, Greene County	1.572	.020		
218	Clay prospect pit NW. 1/4 Sec. 29—T12N—R12W, Greene County	1.565	.020	"	"
248	W. S. Shaw Co., Berdan, Greene County	1.562	.020	Medium(?)	"
	Underclay below the Seahorne limestone of the lower Pottsville				
284	Alsey Brick and Tile Co., Alsey, Scott County	1.566	.020	Small	"
274	Alton Brick Co., Alton, Madison County	1.566	.020	"	"
271	Stoneware Pipe Co., East Alton, Madison County	1.562	.020	"	"
	Underclay of coal No. 2				
206	Chicago Retort and Firebrick Co., Ottawa, LaSalle County	1.558	.018	"	"
208	Mid-West Brick Co., Tonica, LaSalle County	1.560	.020	"	"
211	Same as 208, but higher in exposed section	1.564	.020	"	"
225	Hydraulic Press Brick Co., Sparland, Marshall County	1.569	.020	"	"
	Underclay of coal No. 6				
205	Streater Clay Mfg. Co., pit southeast of Streator, Livingston County	1.560	.020	"	

Illinois State Geological Survey
Urbana, Illinois

ACTIVITIES OF THE SOCIETY

ENAMEL DIVISION RESEARCH COMMITTEE REPORT

This Committee, composed of G. H. McIntyre, W. H. Pfeiffer, J. J. Canfield, A. I. Andrews, and R. M. King, has coöperated with the Bureau of Standards and the Educational Bureau of the Porcelain Enamel Institute in formulating their research program. Several of the members of this Committee are also members of the Bureau of Standards Advisory Committee and of the Technical Section of the Educational Bureau of the Porcelain Enamel Institute. Mr. Harrison has reported on the work being planned at the Bureau.

The work of the Technical Section proposed to date is (1) a study of the design of enamel products, (2) development of a more definite nomenclature, (3) development of a patching compound, and (4) development and selection of standard tests.

In view of the activities of the Technical Section and its strong industrial sponsorship, the question has arisen as to what the Research Committee of the Division can do to justify itself without duplication of activities. It would seem that in the nature of things this Committee can be advisory only and further that in view of the activities of the Technical Section it had best confine its efforts to the more fundamental phases of enamel research.

In making a survey of the literature of the past year and of the present work of the various laboratories, we find the following fundamental problems being studied:

(1) Coefficient of Expansion, Tensile Strength, and Other Fundamental Properties of Enamels. U. S. Bureau of Standards.
(2) Halloysite as a Suspending Medium in Enamel Slips. Missouri School of Mines.
(3) Thermal and Chemical Reactions During the Smelting of Enamels. University of Illinois.
(4) The Solubility of Aluminous Silicates in Glasses. North Carolina State College.
(5) Adherence, Reboiling, Suspension in Enamel Slips, and Grain Size in Steels in Relation to Enameling Properties. Ohio State University.—R. M. KING, *Chairman*.

CHARLES FERGUS BINNS MEMORIAL SERVICES TO BE HELD AT ALFRED UNIVERSITY, JUNE 8

At 11:00 A.M. on June 8, the Faculty, students, and alumni of Alfred University and many friends of Dr. Binns from various parts of the country will assemble in front of the Old Ceramic Building of the New York State College of Ceramics to pay tribute to this great pioneer in ceramic education who passed away December 4, 1934. The Committee, consisting of Dean M. E. Holmes, Chaplain J. C. McLeod, Prof. M. L. Fosdick, Rev. A. C. Ehret, and The Rev. J. G. Spencer, has arranged the following program:

(1) Processional. (The speakers, faculty, and students, in academic costumes will proceed from the "Gothic" to the "Old Ceramic Building.")
(2) Invocation by The Reverend A. C. Ehret, Pastor of the Village Church.
(3) Music.
(4) Memorial Address by Prof. Paul E. Cox, Head of the Department of Ceramic Engineering, Iowa State College, Ames, Iowa.
(5) Music.
(6) Address: "Charles Fergus Binns, My Colleague" by Boothe C. Davis, President Emeritus, Alfred University.
(7) Address: "Charles Fergus Binns, the Christian" by The Reverend J. G. Spencer, Rector of Christ Church, Hornell, N. Y.
(8) Address: "Charles Fergus Binns, the Ceramist" by J. M. McKinley, President of the American Ceramic Society.
(9) Address: "Charles Fergus Binns, the Educator" by M. E. Holmes, Dean, N. Y. State College of Ceramics.
(10) Music.
(11) Dedication of the Old Ceramic Building as "Binns Hall." J. Nelson Norwood, President of Alfred University.
(12) Benediction: The Reverend J. C. McLeod.

All who have ever known Dr. Binns will want to attend these services and they are invited and urged to do so.

—M. E. HOLMES, *Dean*.

Ten Members Elected to the Fellowship of the American Ceramic Society

The following members of the Society were elected to the Fellowship February 18, 1935:

Elliott E. Geisinger, The Pfaudler Werke A. G. Schwetzinger, Baden, Germany.

Donald Alonzo Moulton, Iowa State College, Ames, Iowa.

William Victor Knowles, 1150 Sylvania Road, Cleveland Heights, Ohio.

Erwin Sohn, Standard Sanitary Mfg. Co., 1541 S. 7th St., Louisville, Ky.

Charles Rhodimer Amberg, Box 122, Alfred, N. Y.

Donald Hagar, 1135 Brighton Blvd., Zanesville, Ohio.

Frederick Louis Steinhoff, *Brick & Clay Record*, 59 East Van Buren St., Chicago, Ill.

Richard Smith Bradley, 1005 South Clark, Mexico, Mo.

Clyde Lowry Thompson, 204 Ceramics Bldg., Univ. of Illinois, Urbana, Ill.

Samuel Forman Walton, Sr., The Exolon Company, Blasdell, N. Y.

MEMBER AND SUBSCRIBER STATUS APRIL 15, 1935

	Personal	Corporation	Total Circulation
Paid in full	1069	171	
Deferred	84		
Part-payment	56		
Honorary, Life, and Complimentary	29		
Subscribers	383		
Advertisers		31	
	1621	202	1823
Current Sales			200
			2023

These data almost duplicate those of the fall months of 1934.

When shall we again have 2700 paid members?

OUR RECORD OF INCOME AND EXPENSE*

For 1931, 1932, 1933, 1934, and the FIRST QUARTER of 1935

	1931	1932	1933	1934	3 Months of 1935
Income					Earned
Dues	$26,443.34 58.5%	$21,128.53 61.6%	$15,437.68 55.6%	$15,943.06 57.2%	$4,665.28 52.5%
Advertising	$10,856.37 23.9%	$ 7,929.78 23.2%	$ 6,522.82 23.4%	$ 7,424.95 26.6%	$2,514.64 28.3%
Miscellaneous	$ 7,954.79 17.6%	$ 5,197.41 15.2%	$ 5,852.76 21.0%	$ 4,527.87 16.2%	$1,709.12 19.2%
Total Income	$45,254.50	$34,255.72	$27,813.26	$27,895.88	$8,889.04
Expense					
Publications	$33,371.49 76.5%	$24,359.84 73.4%	$22,906.00 76.2%	$22,751.42 73.5%	$6,099.72 72.6%
General	$10,262.07	$ 8,816.77	$ 7,157.13	$ 8,202.49	$2,302.22
Gain or Loss	G-1,620.94	G-1,079.11	L-2,249.87	L-3,058.03	G-487.10

Totaling the number of members, subscribers, and advertisers on April 15, there were 1823. This number, divided into $6099.72, shows that the Society has spent $3.35 per subscriber on publications this first quarter of 1935. This is below the average, as the above table shows, for the previous four years.

This $3.35 per subscriber in three months means that $13.38 will be spent on publications for each subscriber during the year 1935.

The data show that $12.50 personal dues do not cover the cost of publications which each member receives. Money with which to pay general expenses must be derived from sources other than personal dues.

These data show necessity for Corporation Members at the minimum annual subscription of $25.00 to pay the general expenses and to keep personal member dues within the limit of the average personal member's ability to pay.

If the Society is to publish reports of original researches and abstracts of world-wide literature and is to promote ceramic research and education to the extent afforded and needed, the income from advertising must be increased.

*** Graphic arts code has boosted printing and paper costs. General expenses are now at minimum; an increase in this amount can not be avoided. The Society must have more income from dues in 1935 to render services equivalent to those rendered in 1934. With more members, the advertising income will increase—if you, our members, will secure more advertising.**

BERNARD MOORE† AND ALBERT GRANGER HONORED

Bernard Moore, Stoke-on-Trent, England, and Dr. Albert Granger, 212 Boulevard Pereire, Paris XVII, France, were elected to Honorary Membership in the American Ceramic Society by action of the Board of Trustees during the Annual Meeting in Buffalo, N. Y., February 18, 1935.

† Word has recently been received by the General Secretary of the American Ceramic Society that Mr. Moore passed away April 3, 1935.

NEW MEMBERS

CORPORATION

Rustless Iron Co., Ltd., H. Whitaker (voter), Trico Works, Keighley, England.

PERSONAL

Albers-Schönberg, Ernst, Florastrasse 8, Berlin-Pankow, Germany; director Steatit-Magnesia Akt.-Ges.

Barrett, Elliott P., Mineral Industries Bldg., State College, Pa.; professor, Pennsylvania State College.

Burr, E. A., 1125 Builders Exchange Bldg., Cleveland Ohio; secretary, Cleveland Quarries Co.

Fellinger, Hermann, Westfalischstrasse 90, Berlin-Wilmersdorf, Germany; Didier-Werke Akt.-Ges.

Green, John R., Brown Instrument Co., Philadelphia, Pa.; manager, Ceramic Division.

Goerz, Adolf, Apartado 508, Mexico, D. F., Mexico; director of the chinaware factory, "Fabrica de Loza El Anfora," S. A.

Hallsworth, Stanley, 1 Douglas Ave., Ward End, Birmingham, England; manager, Porcelain Enameling Dept., The Parkinson Stove Co., Ltd.

Harding, Russell, P. O. Box 508, Ottawa, Ill.; research asst., Chicago Retort and Fire Brick Co.

Hibbins, T. A., The Stevenson Co., Wellsville, Ohio.

Hilder, Albert E., 706 Concourse Bldg., 100 Adelaide St., West, Toronto, Canada; managing-director, General Refractory Products, Ltd.

Keaney, Joe C., 240 Inglewood Drive, Mt. Lebanon, Pittsburgh, Pa.; chemist and sales engineer.

Kirchner, J. E., Tovaros, Hungary; mechanical engineer.

Kleist, Dale, 68 N. 2nd St., Newark, Ohio; research engineer, Ind. Mat. Division, Owens-Illinois Glass Co.

Kremers, H. C., Charles Lennig & Co., Inc., Richmond & Kennedy Sts., Philadelphia, Pa.

Lassman, Benjamin, Oliver Bldg., Pittsburgh, Pa.; president-treasurer, Hydraulics Inc.

Matthews, Leslie G., 120 Broadway, New York, N. Y.; asst. sales manager, American Smelting & Refining Co.

Nichols, A. S., 608 S. Dearborn St., Chicago, Ill.

Rosenberg, Jacob E., 5331 Beeler St., Pittsburgh, Pa.; director of research, O. Hommel Co.

Schwendler, Richard H., 3550 Woodridge Road, Cleveland Heights, Ohio; general superintendent, Enamel Products, Eddy Rd. & Taft Ave.

Swinnerton, George R., 529 Vincent Blvd., Alliance, Ohio; sales representative, Moore & Munger, 33 Rector St., New York.

Tucker, Jesse LeRoy, P. O. Box 494, Newark, Ohio; research engineer, Ind. Mat. Division, Owens-Illinois Glass Co.

STUDENT

Couch, Albert H., College of Mines, Univ. of Washington, Seattle, Wash.

MEMBERSHIP WORKERS' RECORD

Corporation

Office	1

Personal

P. E. Cox	1	N. H. Stolte	1
F. C. Flint	1	John H. Thomas	2
R. D. Landrum	1	E. H. Van Schoick	1
J. M. McKinley	1	F. J. Williams	1
J. T. Robson	1	Office	9
S. Rusoff	1		
W. Steger	1	Total	21

Student

E. G. Couch	1
Grand Total	23

ROSTER CHANGES DURING APRIL

CORPORATION

Roberts & Mander Stove Co., Donald H. Fuller (voter), Hatboro, Pa. (Robert B. Schaal, voter.)

Rundle Manufacturing Co., H. J. Held (voter), 3905 River Rd., Camden, N. J. (Milwaukee, Wis.)

PERSONAL

Beverley, Reginald A., 126 N. Prospect Ave., Park Ridge, Ill. (722 Wisner Ave.)

Cone, Carroll, 319 E. 4th St., Alton, Ill. (Columbus, Ohio.)

Couch, E. G., Jr., 319 E. 4th St., Alton Ill. (Darlington, S. C.)

Fairchild, T. M., 737 Franklin St., Johnstown, Pa. (Portville, N. Y.)

Czolgos, Edmund P., 4155 E. 71st St., Cleveland, Ohio. (Chicago, Ill.)

Emley, William S., New Castle Refractories Co., New Castle, Pa. (Washington, N. J.)

French, Myrtle M., 800 S. Halsted St., Chicago, Ill. (Art Institute of Chicago.)

Hedquist, Alfred J., Box 594, Norris, Tenn. (Elyria, Ohio.)

Knight, Frank P., Jr., 19 Harbor St., Manchester, Mass. (West Paris, Maine.)

Kurtz, Thomas N., North American Refractories Co., Oliver Bldg., Pittsburgh, Pa. (Mt. Union, Pa.)

Littlefield, Edgar, 175 W. California Ave., Columbus, Ohio. (2317 Neil Ave.)

McDowell, Samuel J., General Ceramics Co., Keasbey, N. J. (AC Spark Plug Co., Flint, Mich.)

Manson, M. E., Lake Bluff, Ill. (Chicago Hardware Foundry Co., N. Chicago, Ill.)

Montgomery, E. T., Smith & Stone, Ltd., Georgetown, Ont., Canada. (Montgomery Porcelain Products Co., Franklin, Ohio.)

Parsons, Joseph R., Chicago Fire Brick Co., 1451–67 Elston Ave., Chicago, Ill. (7531 S. Ashland Ave.)

Thompson, Thomas C., 1419 Central Ave., Wilmette, Ill. (1311 Ashland Ave.)

Thornton, Paul E., 20 N. Caroline St., Crystal Lake, Ill. (Chicago, Ill.)

Twells, Robert, % John MacKillop, 27 N. Holcomb St., Clarkston, Mich. (Flint, Mich.)

Wheeler, D. D., 2704 Green Garden Blvd., Erie, Pa. (1347 W. 30th St.)

Winburn, H. L., 709 Rector Bldg., Little Rock, Ark. (134 S. Oak.)

Wong, On Yuen, Taishan Brick and Tile Co., Loonghua Junction, Shanghai, China. (Y. S. Fond Co.)

OFFICIAL DIVISION PERSONNEL 1935–1936

(For List of Society Officers and Standing Committees, see the April *Bulletin*, p. 146.)

	Art*	Enamel	Glass	Materials and Equipment	Refractories	Structural Clay Products	Terra Cotta	White Wares
Trustee	F. H. Rhead	W. C. Lindemann	J. T. Littleton	V. V. Kelsey	R. B. Sosman	R. B. Keplinger	R. L. Clare	P. D. Helser
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Vice-Chairman			J. S. Gregorius	H. B. DuBois	R. E. Birch			
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Editorial	F. H. Rhead R. G. Cowan H. S. Nash	T. D. Hartshorn R. D. Cooke B. A. Rice	G. V. McCauley G. E. F. Lundell E. W. Tillotson	C. C. Treischel J. E. Eagle G. H. Brown	H. E. White R. B. Sosman R. K. Hursh	Ellis Lovejoy J. O. Everhart J. W. Whittemore	H. G. Schurecht H. E. Davis E. C. Hill	S. J. McDowell R. F. Geller H. F. Vieweg
Papers and Program	F. H. Rhead R. G. Cowan	G. H. McIntyre Frank Porter Warren Copp N. G. Wedemeyer	J. S. Gregorius	H. F. Kleinfeldt	N. W. Taylor K. W. Smith S. F. Walton	W. C. Rueckel	J. L. Carruthers	V. J. Roehm
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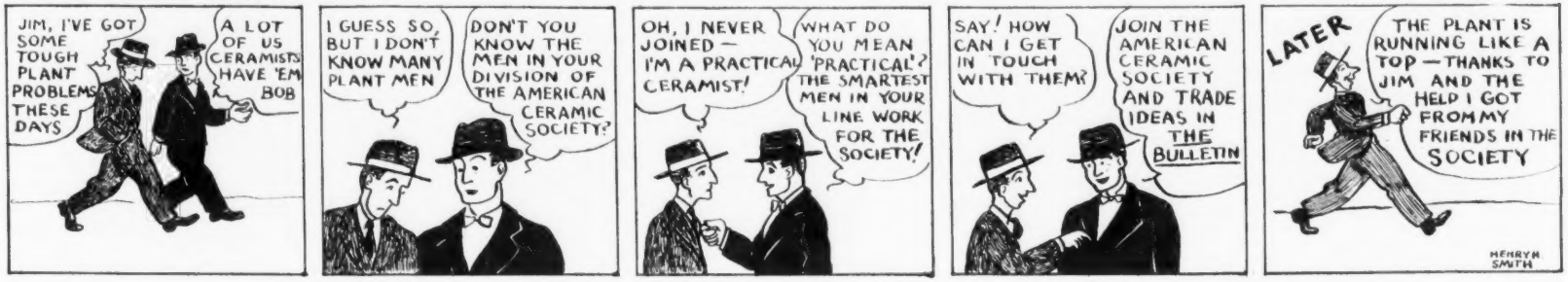
Education	H. S. Nash	W. H. Pfeiffer	J. C. Hostetter	B. T. Bonnot	F. A. Harvey	D. A. Moulton		A. S. Watts
Data		C. R. Amberg	A. N. Finn	G. F. Metz		T. W. Garve		G. A. Loomis
Rules	L. E. Barringer	R. D. Landrum	W. M. Clark	Fred Bell	K. E. Buck	Howells Frechette		Edward Schramm
Management		H. E. Ebright		F. A. Guignon	C. E. Bales	C. F. Tefft		Donald Hagar
Statistics		K. R. Groener		G. W. Cooper	L. C. Hewitt			J. R. Beam
Councillors		Frank Hodek R. B. Schaal W. N. Harrison A. I. Andrews	G. W. Morey Herbert Insley	Philip Dressler R. L. Caywood				Edward Schramm
Exhibitions	R. G. Cowan			Tom Falknor				Tom Falknor
Symbols and Nomenclature					F. J. Williams E. P. Barrett			

* Temporary; chart of reorganized Art Division will appear later.

Wise Jim and Unhappy Bob


JIM, I'VE GOT SOME TOUGH PLANT PROBLEMS THESE DAYS
A LOT OF US CERAMISTS HAVE 'EM BOB
I GUESS SO, BUT I DON'T KNOW MANY PLANT MEN
DON'T YOU KNOW THE MEN IN YOUR DIVISION OF THE AMERICAN CERAMIC SOCIETY?
OH, I NEVER JOINED — I'M A PRACTICAL CERAMIST!
WHAT DO YOU MEAN 'PRACTICAL'? THE SMARTEST MEN IN YOUR LINE WORK FOR THE SOCIETY!
SAY! HOW CAN I GET IN TOUCH WITH THEM?
JOIN THE AMERICAN CERAMIC SOCIETY AND TRADE IDEAS IN THE BULLETIN
LATER
THE PLANT IS RUNNING LIKE A TOP — THANKS TO JIM AND THE HELP I GOT FROM MY FRIENDS IN THE SOCIETY
HENRY M SMITH

REPORT OF THE COMMITTEE ON THE CHEMICAL DURABILITY OF GLASS

Part I Committee Activities

At the symposium on Chemical Durability of Glass, held by the Glass Division at Lake Keuka, September 14 to 15, 1934, a committee was appointed to initiate a program and commence an investigation of the subject. The members of the committee were D. E. Sharp, *Chairman;* U. E. Bowes, W. F. Brown, F. C. Flint, J. C. Hostetter, G. W. Morey, and W. C. Taylor.

The first meeting was held at the Bureau of Standards on October 8, and the coöperation of the Bureau was obtained in several important respects. G. E. F. Lundell was added to the committee, and arrangements were made for him to collect and correlate data obtained from the various laboratories.

Plans were made to obtain large samples of several representative glasses, which were to be stored at the Bureau and sent out by Dr. Lundell as required. Several such sets of samples were ultimately acquired through the generosity of various glass manufacturers, and these comprise the following:

3 bottle glasses
2 sheet glasses
1 polished plate glass
1 tubing glass
1 rod glass

The aid of twenty-one coöperators was enlisted and it was decided to send specifications of a tentative method to each, along with a sample glass, and to correlate the results reported before taking further steps.

The list of coöperators is as follows:

American Optical Co., H. R. Moulton.
Bailey & Sharp Co., D. E. Sharp and W. Horak.
Bausch & Lomb Optical Co., T. J. Zak and S. V. Peterson.
Carr-Lowrey Glass Co., C. B. McComas and R. Schlehr.
Corning Glass Works, W. C. Taylor and H. S. Willson.
Hartford-Empire Co., V. C. Swicker.
Hazel-Atlas Glass Co., F. C. Flint and A. K. Lyle.
Libbey Glass Mfg. Co., H. R. Black.
Libbey-Owens-Ford Glass Co., R. W. Wampler.
Macbeth-Evans Glass Co., H. H. Blau.
Maryland Glass Co., L. C. Roche and W. R. Lester.
National Bureau of Standards, A. N. Finn.
N. Y. State College of Ceramics, S. R. Scholes.
Ohio State Univ., R. M. King.
Owens-Illinois Glass Co., U. E. Bowes and O. G. Burch.
Pennsylvania State College, N. W. Taylor.
Purdue Univ., K. Lark-Horovitz.
Rutgers Univ., H. F. Vieweg.
Sharp-Schurtz Co., D. D. Schurtz.
Univ. of Illinois, C. W. Parmelee and A. E. Badger.
Univ. of Pittsburgh, A. Silverman and C. J. Engelder.

The prime purpose of the Committee was understood and stated to be the study of durability methods, with the hope and expectation that ultimately it would be possible to recommend methods that could be considered as standards of procedure. It was recognized at the outset that no one method could be expected to be applicable to all types of glass, and that it would be necessary to have more than one, and possibly several different methods, each applicable to certain definite needs.

In this connection it was recognized that a "surface" test of some type would ultimately be needed; that a specification of results by "alkali dissolved" would be inapplicable to many of the special types of glass, and that peculiarities of manufacture and use would have to be taken into account in various ways.

Accordingly, it was determined that the Committee should not attempt to set up any standards whatsoever of what constitutes "good" or "bad" glass, but that they should adhere strictly to a program of developing standard methods of testing and of ascertaining the sources of variation in the methods.

With the above ideas in mind, the Committee decided first to study methods applicable to glass "as glass" which involve the testing, in some manner, of a sample prepared by crushing or grinding the glass to a powder. Due progress was made in this preliminary study, and a summary of the results, abridged from reports to the committee by Dr. Lundell, is given in Part II of this report.

At a meeting of the committee held in Buffalo at the time of the Annual Meeting of the Society, February 17 to 23, it was decided to prepare a restatement of the tentative method discussed in Part II and to have further tests made by this method by a limited few of the coöperators before proceeding with further studies. Further examination of the British and German methods was planned, but the differences in the screen size from those available in America were looked on as a decided objection to the methods.

The purposes of the investigations were reiterated to be the study and development of several standard methods of testing, and not the development of standards of quality.

It was pointed out also that the committee did not, as yet, take the position of recommending the tentative method to the glass industry, and that considerable further progress should be gained before definite recommendations could be made.

In order to simplify operations, it was suggested that further work should be carried out under the Standards Committee of the Glass Division. With this in mind, the Committee on Chemical Durability was discharged by the formal action of the Division and its duties transferred to the regular Standards Committee.

Part II. Details of Results by Tentative Method No. 1

The method that was chosen for preliminary study is one in which the durability of the glass is represented by the Na_2O equivalent of the acid that is neutralized when a powdered sample of the glass is digested for four hours at 90°C in $N/50$ sulfuric acid.

Special equipment needed in this method are (1) a special hardened steel mortar with a flat-bottom 2-in. cavity and a flat-bottomed pestle; (2) a nest of sieves, one 40 (0.417 mm. or 35 meshes/in.), one 50 (0.295 mm. or 48 meshes/in.), and one 20 (merely to protect the 40); and (3) a thermostatically controlled electrically heated

water-bath capable of maintaining a temperature constant to ±0.5°C. The use of a Ro-Tap machine is optional.

Briefly sketched the method is as follows: Crush three or four 30- to 40-gram portions of glass by striking the pestle sharply with a hammer 3 or 4 times. Empty on to the set of sieves. Shake by hand for 2 minutes, remove the particles on the 20 and 40 sieves, and recrush them as before. Repeat this once again. Place the nest on a Ro-Tap machine and shake for 5 minutes or shake by hand for 3 minutes, using a rotary motion following a circle about 6 in. in diameter and making about 120 r.p.m.

Transfer the material on the 50-mesh sieve to a sheet of paper and treat with a magnet. Transfer to a $1^1/_2$- by $1^1/_2$- by $1^1/_2$-in. basket made of 80-mesh copper screen, and agitate for about 1 minute in distilled water and 1 minute each in two changes of alcohol. Dry at 110°C in an oven or at 300 to 400°F over a hot plate and then cool for 15 to 20 minutes in a desiccator.

Transfer a 10-gram sample to a 200 ml. Erlenmeyer flask of Pyrex brand glass, add 50 ml. of $N/50$ H_2SO_4, stopper with a one-hole stopper, and immerse to a depth of about 2 in. in the bath. Heat at 90°C ±0.5° for 4 hours. Remove the flask, cool quickly in running water, and add phenol red indicator. Add $N/50$ NaOH (free from CO_2) until in about 1 ml. excess, and then titrate with $N/50$ H_2SO_4 until the color changes from red to yellow. Calculate according to the formula

$$\text{Per cent } Na_2O = \frac{(\text{ml. } N/50\ H_2SO_4 \text{ used} - \text{ml. } N/50 \text{ NaOH used}) \times 0.00062 \times 100}{10}$$

The results that were obtained in tests on a sample of bottle glass by the chosen method are shown in Table I, in which the numbers assigned to the coöperators have no relation to their order in the list. It will be noted that some of the coöperators departed from the assigned method in one respect or another. This did not yield a fair test of the method but did reveal some of its pitfalls.

After the coöperators had completed the tests shown in Table I, it was thought that better agreement might be had if special attention were given to details in the preparation of the sample and if all tests were completed on the day that the sample was prepared. Seven of the coöperators were chosen to make re-tests on sample No. 1, as well as new tests on a sample of sheet glass. This work is summarized in Table II, together with a test of the sheet glass by coöperator No. 16.

It will be noted that the results reported by the three cooperators who adhered closely to the method showed excellent agreement with the selected average (0.068) for sample No. 1, and among themselves for the sheet glass, while the results reported by the four coöperators who did not adhere closely showed greater deviation from the selected average for sample No. 1 and higher results for the sheet glass. Especially noteworthy is the change from 0.111 to 0.067 in the case of coöperator 21 as a result of substituting the standard 2-in. mortar for a 1-in. mortar.

Discussion

For the purpose of discussion, method 1 can be divided into the following six steps: (1) crushing, (2) sieving, (3) washing and drying, (4) storing, (5) digesting, and (6) titrating. These will be taken in order.

TABLE I

FIRST RESULTS REPORTED BY COÖPERATORS IN TESTS OF BOTTLE NO. 1 BY METHOD NO. 1

Coöperator	Averaged result	Spread of results	Mortar	Remarks
1	0.047	0.047–0.047	S	Sample stored in open for 2 wks.
2	.054	.053– .055	Agate	Digestion at boiling temperature
3	.059	.055– .065	Braun disk	Bromphenol blue indicator
4	.060	.060– .060	S	Gas-heated bath which varied
5	.063*	.062– .064	S	
6	.063*	.058– .067	S	Bromthymol blue indicator
7	.063*			Sample washed with HCl
8	.065*	.060– .068	S	Sample washed with HCl
9	.065*	.063– .068	S	
10	.066*	.064– .068		
11	.067*	.066– .068	2″	Acid - washed sample gave 0.063–0.068
12	.069*	.068– .070	S	
13	.070*	.069– .070	S	
14	.070*	.069– .070	S	Sample washed with HCl
15	.071*	.071– .071	$2^1/_2$″	
16	.072*	.071– .073		
17	.075*	.074– .076	2″	
18	.078	.074– .081	1″	
19	.080		?	Sample washed with HCl
20	.093		$^5/_8$″	Digestion at 92.5 ±1.5°C
21	.111	.110– .111	1″	

* Reasonable adherence to method No. 1.

Rounded average of results obtained by reasonable adherence to method 1—0.068.

Average deviation of these selected results from rounded average—0.003.

Number of selected results within average deviation, approx.—60%.

Number of selected results within 0.005 of the rounded average, approx.—90%.

Number of all results within 0.005 of the rounded average, approx.—60%.

(*1*) *Crushing*

It is strongly recommended that the standard mortar be used, for otherwise no intercomparison between laboratories is possible. This can be illustrated by the experience of coöperator 21, and by the results reported by cooperator 20 (who used a $^5/_8$-in. mortar) and coöperator 17 (who used a 2-in. mortar with a round instead of a flat cavity). It is emphasized that the sample be broken by impact and not by grinding.

(*2*) *Sieving*

Undoubtedly a common fault in the work was the use of too much sample on the 50-mesh sieve. The ideal amount is apparently about 11 and the upper limit about 25 grams. Coöperator 21, for example, obtained an average value of 0.067 when the 40 to 50 portion weighed 20 to 25 grams and 0.073 when it weighed 45 grams. The need for thorough sieving can also be illustrated by special tests

TABLE II

RESULTS OBTAINED IN SECOND TRIAL OF METHOD

Coöperator	Bottle No. 1 1st Trial	2nd Trial	Sheet Glass	Remarks
3	0.066 (0.060–0.068)	0.080 (0.078–0.081)	0.027 (0.026, 0.027)	Braun disk grinder } Crushed sample was large and not washed
		0.085 (0.083–0.086)	0.027 (0.027–0.027)	Crushed by impact }
4	0.060 (0.060–0.060)	0.074 (0.074, 0.074)	0.027 (0.027, 0.027)	Gas-heated water bath whose temperature varied more than ±0.5° from 90°C
6	0.063 (0.058–0.067)	0.069 (0.068–0.070)	0.019 (0.019–0.020)	Used standard method except for bromthymol blue as indicator
11	0.067 (0.066–0.068)	0.068 (0.067–0.069)	0.019 (0.018–0.020)	Used standard method
17	0.075 (0.074–0.076)	0.076 (0.076, 0.076)	0.025 (0.025, 0.025)	2-in. mortar with rounded cavity
20	0.093	0.085 (0.081, 0.089)	0.031 (0.031, 0.031)	Mortar $^5/_8$ in. and temperature 92.5 ± 1.5°C
21	0.111 (0.110–0.111)	0.067 (0.065–0.068)	0.020 (0.020–0.021)	1-in. mortar used in 1st trial, standard mortar in 2nd trial
16	0.072 (0.071, 0.073)		0.019 (0.019–0.020)	Used standard method

made by coöperator 12 who obtained 0.043 with the 20 to 40, 0.068 with the 40 to 50, 0.089 with the 50 to 60, and >0.3 with the material in the pan. In this connection it should be noted that the total surface area of the particles in a 10-gram sample of 50-mesh is about twice that of a 40-mesh glass.

There is no evidence that results will be seriously disturbed if the sieving is continued by hand until little or no material passes the 50 sieve.

Where nested sieves are used, the bottom pan should be emptied before the final sieving.

(3) Washing and Drying

The need for washing can be illustrated by results 0.076 and 0.077 obtained with samples that were thoroughly screened but not washed, as compared with 0.066 and 0.067 obtained with samples that had been washed with water and alcohol. It is recommended (1) that the sample be held in a 50-mesh instead of an 80-mesh container during washing, (2) that the container be large enough to permit free movements of all particles, and (3) that the alcohol be tested to make sure that it is neutral. One coöperator successfully washed and dried the sample in the 50-mesh sieve.

The effect of washing with diluted HCl (1 + 99) is so slight (about 0.065 as against 0.068) in comparison with possible errors attending its use that such washing had better be abandoned.

Drying at 110°C in an oven or at 150 to 200°C over a hot plate is optional. It is recommended that the dried sample be cooled in a desiccator containing an efficient desiccant.

(4) Storing

The safest procedure lies in planning the work so that all operations can be completed within 12 hours. The gradual change in samples stored under ordinary conditions can be illustrated by tests in which portions of the glass were carefully crushed and screened while the relative humidity was 60% and put in flasks which were immediately stoppered. Tests showed 0.071 on a portion that was washed and tested immediately, as against 0.068, 0.065, 0.064, and 0.064 on portions that were washed and tested after storage from 24, 48, 96, and 192 hours, respectively. On the other hand, samples which were *not* washed after storage over $Mg(ClO_4)_2$ showed no appreciable change. This is illustrated in the following tabulation:

Washing procedure	Tested immediately	Tested after 3 days
None	0.076, 0.077	0.074, 0.073
H_2O–C_2H_5OH	.067, .066	.067, .065
HCl–H_2O–C_2H_5OH	.065, .065	.065, .066

(5) Digesting

It is quite obvious that the heating arrangement must be such that the water will quickly come to 90°C after the flasks are put in the bath and will remain within ±0.5° of this temperature during the test. To make for uniformity, it is recommended that the flasks be closed with stoppers having a $^3/_{16}$-in. hole.

In special tests in which the solution was agitated at 15-minute intervals, the results obtained at the end of 1, 2, 3, and 4 hours were 0.043, 0.053, 0.061, and 0.068, respectively. These indicate that moderate agitation does not speed up the attack.

It is interesting to note that sample No. 1 showed less attack (0.052) when water was substituted for $N/50$ H_2SO_4 in the digestion and that one coöperator reported that the p_H of the water extract so obtained was 10.2.

In the digestion with $N/50$ H_2SO_4, all of the constituents of the glass pass into solution, but not in proportion to their amounts in the glass. An analysis of the extract by coöperator 21 showed approximately SiO_2 3%, "R_2O_3" 1%, CaO 2%, MgO 3%, and Na_2O 91%. The calculated weight of the constituents that were extracted was 0.0077 gram as compared with the 0.0068 gram of "Na_2O" represented by titration.

(6) Titrating

Some coöperators expressed a preference for indicators other than phenol red, *e.g.*, phenolphthalein, methyl red, bromthymol blue, and bromphenol blue. There is no apparent reason why another indicator can not be substituted provided (1) it yields a satisfactory end point with the dilute acid solution that is used, (2) it is employed in all of the operations, and (3) carbon dioxide is excluded if the indicator is sensitive to it.

The operator should satisfy himself as to the need for corrections by carrying the *N*/50 acid through the digestion. Pyrex brand flasks apparently "age" rapidly as illustrated in the following tests on new flasks:

Digestion	Grams of dissolved alkali as Na_2O
1st	0.00040
2nd	.00022
3rd	.00012
4th	.00003

Modifications

The following modifications of test method No. 1 were suggested:

(1) Substitute a 28-mesh sieve for the No. 20, and crush all of the sample to pass the 28-mesh.
(2) Omit washing of sample.
(3) Wash and dry sample on the 50-mesh sieve.
(4) To avoid temperature lag at the start of the digestion, heat flask and acid to 90°C and then add the sample which has been heated to 90°C.
(5) Stir the solution during the digestion.
(6) Increase the amount of dissolved alkali by using finer particles or extending the time of digestion.
(7) Define the preparation and standardization of solutions in detail.
(8) Use indicators other than phenol red.
(9) Blank determinations should be mandatory.

Comparative Tests

Special tests on sample No. 1 by the Flint-Lyle autoclave method gave values of 0.073 and 0.071 gram of NaOH per liter.

Special tests on sample No. 1 by a modification of the Sheffield method in which a grain size of 0.295–0.417 mm. was substituted for 0.42 to 0.635 mm. gave an alkalinity of 0.048% Na_2O.—COMMITTEE ON THE CHEMICAL DURABILITY OF GLASS.

MARCH 15, 1935

OUR THIRTY-EIGHTH ANNUAL MEETING, COLUMBUS, OHIO, MARCH 29 to APRIL 4, 1936

Note the fact that the 1936 Meeting of the Society will be held during a week when it is delightful to motor and at the geographic center of industrial ceramics.

Ceramic Ware Firing will be a symposium topic. The need and the method of obtaining thermal history that will develop best the desired properties in our several ceramic wares will be discussed.

The Division officers and members of committees are planning their technical session programs.

The Local Committee is organizing to make that week in Columbus most pleasant for all ceramists. The Deshler-Wallick Hotel and the Neil House have made ample room reservations so that all meetings will be held in the hotels.

The Chamber of Commerce has pledged its full support.

The Ohio State University, The Battelle Memorial Institute, The Edward Orton, Jr. Ceramic Foundation, the Ohio Ceramic Industries Association, and The American Ceramic Society are joining with Columbus officials in making plans for this 1936 Annual Meeting of the Society.

EXECUTIVE SUMMER MEETING AT HORNELL, N. Y., JUNE 7

President J. M. McKinley has called a meeting of the Board of Trustees, Division and Local Section Officers, and members of Committees to be held at Hornell, N. Y., Hotel Sherwood, on June 7, 1935, at 2:00 P.M. Ways and means of vitalizing the Society to promote the ceramic arts, science, and technology more effectively will be considered.

DIVISION SUMMER MEETINGS

The Art, Glass, Refractories, and White Wares Divisions of the Society will hold informal technical and fellowship meetings in the late summer. Schedules and places of these meetings will be announced in succeeding issues of *The Bulletin*.

LOCAL SECTION NEWS

MICHIGAN-NORTHWESTERN OHIO SECTION HEARS J. T. LITTLETON

Thirty-five members of the Michigan-Northwestern Ohio Section responded to an invitation of the Detroit Engineering Society to join them in their dinner meeting of March 22, 1935.

J. T. Littleton, chief physicist, Corning Glass Works, gave an interesting and instructive lecture on "Glass as an Engineering Material," showing how the properties of certain glasses lend themselves to certain desirable applications. Many specific uses of glass articles were discussed and illustrated by slides, table experiments, and an exhibit of samples. Two motion pictures were presented, one showing the pouring of a large telescope mirror and the other giving statistics on highways throughout the country.

The meeting was held at Hotel Fort Shelby in Detroit.

PITTSBURGH SECTION HONORS DEAN AND MRS. HOLMES

The Pittsburgh Section held their monthly meeting combined with an informal dinner honoring Dean and Mrs. M. E. Holmes. After the dinner the College Club of Pittsburgh sponsored a bridge party for the ladies while the Section held its regular meeting.

Dean Holmes addressed the members on "New York State College of Ceramics and Its Student Research Work." The speaker presented some interesting points on the work at Alfred. Forty-one members and guests attended the dinner.—EARL C. PETRIE, *Secretary*.

NECROLOGY

C. E. Jackson

C. E. JACKSON

Charles Edwin Jackson, president and general manager of the Warwick China Co., died April 12 in Wheeling, W. Va.

Mr. Jackson was the fifth generation of his family in the pottery business. He was a past Vice - President of the American Ceramic Society, having served in this office in 1917. He became a member of the Society in 1906, an active member in 1912, and was a Fellow of the Society.

Born September 2, 1874, at Staffordshire-on-Trent, England, he came to Wheeling with his parents, the late Mr. and Mrs. Charles E. Jackson, when he was six years old. He attended Wheeling schools and Ohio State University, ex-1902.

The Warwick China Company was founded in Wheeling in 1887 and took its name from Warwick Castle, England. The coat of arms of the House of Warwick is used as the trade-mark of this china company. In 1911 the company began producing china under Mr. Jackson's supervision.

Mr. Jackson was also a member of the Ceramic Society [England]. He is survived by his wife, Lucy Moore Jackson; one daughter, Miss Kathryn Jackson, at home; two brothers and four sisters.

NORTH CAROLINA STUDENT BRANCH ELECTS OFFICERS

The Student Branch of the American Ceramic Society at the Raleigh unit of the University of North Carolina elected the following officers for the academic year 1935–36 at its annual meeting in April: *President*, E. B. Smith; *Vice-President*, R. B. Knox, Jr.; *Secretary*, S. G. Riggs, Jr.; *Treasurer*, J. L. McLaughlin; and *Member-at-Large on Engineer's Council*, W. C. Bell.

Mr. Smith served on the Engineer's Council during the past year and has been one of the leaders in departmental activities for several years. He is a member of Keramos and secretary of the North Carolina chapter. He will receive his B.S. degree in June but will return for graduate work next year.—S. G. RIGGS, JR., *Secretary*.

NOTES AND NEWS

CERAMIC ASSOCIATION OF NEW YORK TO MEET JUNE 7

The Second Annual Convention of the Ceramic Association of New York is to meet June 7 at the New York State College of Ceramics, Alfred Univ., Alfred, N. Y. The following tentative program has been announced:

(1) Meeting of Board of Directors—9:00 A.M.

(2) Morning Session of the Convention—10:00 A.M.

Report of the Secretary-Treasurer.

Quality Control by F. M. Thorman, United States Gypsum Co., Oakfield, N. Y.

Fuels and Combustion (speaker not yet designated).

(*f*) Get-together luncheon. Address by President J. Nelson Norwood, Alfred University.

(3) Afternoon Session.

The Ceramic Raw Materials of New York by D. H. Newland, State Geologist.

Report of the Silicosis Committee and an address on Silicosis by O. I. Chormann, Pfaudler Co., Rochester, N. Y.

The Program of the Ceramic Association of New York.

Elections of officer and members of the Board of Directors for 1935–36.

OHIO CERAMIC INDUSTRIES ASSOCIATION MEETS IN MAY

Tentative Program for Refractories Division

The tentative program for the Refractories Division of the Ohio Ceramic Industries Association, which meets at Oak Hill, Ohio, May 17 is as follows:

(1) Some Comments on the Specifications for Super-Refractories
By J. M. McKinley, North American Refractories Co., Cleveland, Ohio (President, The American Ceramic Society).
(2) Progress Report on the Metal Wear Investigation
By J. O. Everhart, Engineering Expt. Sta., O. S. U. Columbus, Ohio
(3) Recent Advances in the Power-Press Method of Fireclay Brick Manufacture
By R. E. Birch, Harbison-Walker Refractories Co., Pittsburgh, Pa.
(4) A New Method for De-Airing a Dry Press
By C. E. Curtis, Engineering Expt. Sta., O. S. U.
(5) Secondary Expansion of Flint Fire Clays
By J. O. Everhart, Engineering Expt. Sta., O. S. U.
(6) A Furnace for Running High-Temperature Load Tests
By A. G. Allison, Chas. Taylor Sons Co., Cincinnati, Ohio

Tentative Program for Heavy Clay Products Division

The tentative program for the Heavy Clay Products Division of the Ohio Ceramic Industries Association which will meet at the Sleepy Hollow Country Club, Cleveland, Ohio, May 22 is as follows:

(1) Report of Paving Brick Research
By W. C. Rueckel, Director, Paving Brick Research Bureau, O. S. U., Columbus, Ohio
(2) Progress Report on Metal Wear Investigation
By J. O. Everhart, Research Engineer, Engineering Expt. Sta., O. S. U.
(3) De-Airing a Dry Press
By G. A. Bole, Research Professor, Engineering Expt. Sta., O. S. U.
(4) Thermal Expansion of Fireclay Bodies and Its Effect on the Firing of Brick
By J. O. Everhart, Research Engineer, Engineering Expt. Sta., O. S. U.

NOTE: The technical program will follow luncheon at the country club. Golf will follow the program, with prizes being offered for low gross and low net scores.

PORCELAIN ENAMEL INSTITUTE TO MEET IN CLEVELAND

The Porcelain Enamel Institute in Chicago will hold its fifth Annual Meeting at the Hotel Statler, Cleveland, Ohio, May 22. Among the features will be an exhibit showing the type of demonstration to be staged in various stores over the country by the Institute's Educational Bureau.

Typical advertisements to appear in trade publications will also be shown. Copies of the new Sales Manual for Porcelain Enamel will be issued at this meeting.

THIRD CONFERENCE ON GLASS PROBLEMS AT URBANA, ILLINOIS

The Third Conference on Glass Problems will be held May 31 and June 1, 1935 at the University of Illinois under the auspices of the Dept. of Ceramic Engineering, University of Illinois, and of the Chicago Section of the American Ceramic Society.

The program will include papers on glass-tank operation, glass-tank insulation, and the use of cullet. A questionnaire dealing with these problems has been prepared for distribution.—C. W. PARMELEE.

MONTANA SCHOOL OF MINES HOLDS CERAMIC CONFERENCE

The first technical meeting of the Clay Products Manufacturers of Montana and the adjoining states was held at the Montana School of Mines, Butte, Montana, March 29.

The two objectives of the meeting were to unite the clay products manufacturers in the exchange of ideas and the presentation of technical knowledge and to acquaint the manufacturers with the School of Mines and its ceramics program.

Exhibits of the latest products being produced in the ceramic industries were displayed in the ceramics laboratory of the School.

Papers presented at the meeting included (1) "Industrial utilization of gas fuel," by W. W. German, Gas Div., Montana Power Co., Butte, Mont.; (2) "A regenerative drier utilizing latent heat of vaporization," by Walter K. Klose, manager, Missoula Brick and Tile Works, Missoula, Mont., (3) "Refractories, their manufacture and use," by H. H. Goe, superintendent, brick dept., Anaconda Copper Mining Co., Anaconda, Mont.; (4) "A summary of the work and coöperation of the Ceramic Department of the Univ. of Washington," by Hewitt Wilson, director, Dept. of Ceramics, Univ. of Washington, and consulting ceramist, U. S. Bureau of Mines and Montana School of Mines; (5) "The geology of Montana clays," by Eugene S. Perry, director, Dept. of Geology, Montana School of Mines; and (6) "De-airing as applied to the stiff-mud process," by W. W. Kriegel, ceramist, Montana School of Mines.—W. W. KRIEGEL, *Chairman*.

North Carolina Ceramic Graduates Qualify for Examination

The Department of Ceramic Engineering at the Raleigh unit of the University of North Carolina has been notified by the Board of Registration for Engineers of the State of New York that its graduates are qualified to take the examination, the passing of which will permit them to practice engineering in New York. Previous discussions on this subject appeared in *The Bulletin*, pp. 281–82, Oct., 1934; pp. 322–23, Nov., 1934; and p. 46, Jan., 1935.

CARBORUNDUM COMPANY PRESIDENT AWARDED EDWARD GOODRICH ACHESON MEDAL

Frank J. Tone, president of The Carborundum Company of Niagara Falls, N. Y., has been awarded the Edward Goodrich Acheson Medal by The Electrochemical Society. This is the second distinguished award to come to Mr. Tone in recent years; he was the first recipient of the Jacob F. Schoelkopf Medal presented by the Western New York Section of The American Chemical Society.

Highest Honor

The Edward Goodrich Acheson medal was founded in August, 1928, by the late Dr. Acheson, inventor of "Carborundum" and an outstanding figure in electrochemistry. The award is made every two years to "the person who shall have made a distinguished contribution to the advancement of any of the objects, purposes, or activities of the Society," and is the highest honor which can be paid by The Electrochemical Society.

Those who have previously received the Acheson award are Dr. Acheson himself in 1929 for his discovery of the processes of manufacturing "Carborundum" and graphite; Dr. Edwin Fitch Northrup, for his invention and development of the high-frequency induction furnace in 1931; and in 1933, Dr. Colin G. Fink, for a series of achievements in the field of electrochemistry processes for making ductile tungsten filaments and the electroplating of chromium.

Mr. Tone originated the first commercial process for the production of silicon metal, discovered the electric furnace mullite and spinel, and has made important contributions to the commercial development of electric furnace abrasives and super-refractories, particularly silicon carbide and silicon-carbide resistor elements.

Mr. Tone came to Niagara Falls in 1895, where he pioneered in the development of electric furnaces on a large scale. He and his co-worker, F. A. J. Fitzgerald, were the first to apply 1000 h.p. to an electrothermic process and utilized in this manner about half of the entire output of Niagara Falls power. Mr. Tone's work in the abrasive field began in the earliest days of the synthetic abrasive, and it may be said that his guidance has been an outstanding factor in revolutionizing the abrasive industry. Many of the present-day theories of the high-temperature reactions of silica are based directly on Mr. Tone's observations, made in those early days.

Super-Refractories

Paralleling his achievements with electric furnace products in the abrasive field, Mr. Tone is primarily responsible for the present development of the super-refractories industry. He foresaw that price was a secondary matter, compared with specialized refractory service, and he introduced a super-refractory brick at a dollar each, where others competed for business with brick at five cents. His persistence in this field, in the face of the doubts of his associates and frequent unsuccessful trials, were the largest factors in building the refractories division of the Carborundum Company from its early stage of scientific speculation to its present proportions as one of the world's leading producers of refractory products. This refractory division utilizes thousands of tons of silicon carbide, trade-named "Carborundum," in a single year.

F. J. Tone

Mr. Tone has had one hundred and forty-five patents granted to him over a period of 33 years and a number of others are still pending in the United States and foreign patent offices.

The formal presentation of the Acheson Award will be made at the Fall meeting of the Electrochemical Society at Washington, D. C., October 10, 1935.—F. D. B.

Ceramic Engineers at University of North Carolina Win Award

For the fifth time in nine years the Dept. of Ceramic Engineering, Raleigh Unit of the University of North Carolina won the award for the best departmental exhibit at the annual Engineers Fair held April 4 to 6.

R. L. Stone was awarded the second individual prize for a splendid exhibit of art pottery.

Boro-Silico Institute Established in Florence

Under the direction of Prince Ginori Conti, for many years active in the production and use of borax, boric acid, and other compounds of boron, a new industry, the manufacture of optical glass was begun in Italy during the past year. Assistance in starting this enterprise was given the Prince by the French Company of St. Gobain and Parras Mantois.

COMMUNICATIONS

NEW RESEARCHES AND DEVELOPMENTS IN CERAMICS

By Selick I. Perkal

In my opinion articles giving the synthesis of our knowledge in ceramics and a forecast of the future should be published in the section of *The Bulletin* devoted to "Communications."

These articles should stimulate new researches, new developments, and new inventions of tremendous value to the industry. The Society should give special attention to this section, inviting the leading authorities of the world to discuss the problems which are brought to light here.

Participation in this section should be stimulated in every way possible. Only great problems, and questions of real importance should be discussed in these pages. In ceramics there is already a flood of literature, books, periodicals, patents, and trade papers. But there is need for a leading, authoritative, and active organization which would determine what this flood offers the industry. The valuable material should be separated from the remainder and should be arranged for every one to see and to use.

This section of *The Bulletin* could be the clearing house in the field of ceramics. An excellent analysis of the past, giving the picture of outstanding achievements in ceramics history, a constant examination of the present to indicate what we have already attained, and a long projection into the future showing what should be investigated, invented, and developed, all these should be in this section.

I am sure that the American Ceramic Society will find ways and means to summarize and generalize our knowledge and experience thus aiding in the effort to solve the basic problems of ceramics through constant examination of the past, present, and future of this vital industry.

CERAMIC MATERIAL IN SHEETS FOR INSULATING AIR-CONDITIONING SYSTEMS*

With a few rare exceptions, the high-class as well as the average air-conditioning system requires materials which have both heat insulating and acoustical characteristics. In many instances considerable advantage in cost may be gained by the use of material which combines the two characteristics.

Many fibrous and flammable materials combine these two characteristics to a fair degree and have been quite extensively used, particularly in installations which have been designed primarily for a price.

Ceramic material has not been given much consideration because the temperatures producing heat flow were rarely above 125°, and the coefficients of absorption of ceramic materials were low and heat conductivities high; as a consequence of this the materials were high in price.

Two recent instances in which flammable materials have been the cause of fire propagation have caused the underwriters to tighten their restrictions on flammable material.

As a result, an investigation is being conducted to determine what materials that are not flammable are available. Naturally costs must be compared, not on a square foot basis, but on unit figures of cost per unit of conductivity and/or unit of absorption.

For example, of two sheet materials costing the same per square foot, the actual cost on one on the basis outlined above may be double the cost of the other.

Both insulating and sound-absorbing material are required in sheet form, preferably in thicknesses of $^1/_2$ in., 1 in., and 2 in., and in sizes comparable to those in which building or wall boards are produced. It is desirable to have sound-absorbing material in cellular form, similar to the tile in which underground telephone cables are run.

Excessive weight is disadvantageous for either insulating or sound-absorbing material. All companies installing air-conditioning equipment are a possible market for such ceramic material.—Anon.

* Received March 18, 1935.

GLASS: AN INDISPENSABLE FACTOR IN MODERN CIVILIZATION[1]

First American Industry

With the colonization of America the art of glassmaking came to these shores. The first industrial enterprise in the American colonies was a glass factory, located about a mile from Jamestown, Virginia, in 1607.

This first American industry means much to modern civilization. With the introduction of machinery, glass manufacture has grown until it has not only become one of the world's foremost industries but has produced articles which are indispensable to our very existence.

Progress in Glass Technology

Until about fifty years ago glassmaking was a "rule of thumb" process. Then in Europe scientific investigation and control was started.

Thirty-two years ago America had a mere half dozen chemists in the entire industry. Today, hundreds of chemists are ever searching for new ideas and helping engineers and physicists control glass manufacture.

The American Ceramic Society through its membership has made many important contributions to the advancement of ceramic art, science, and technology. Many of its members publish their findings in its publications, *The Journal* and *The Bulletin*.

[1] From a radio talk delivered from station WJAS, Pittsburgh, February 19, 1935, by Alexander Silverman, Head of Dept. of Chemistry, University of Pittsburgh.

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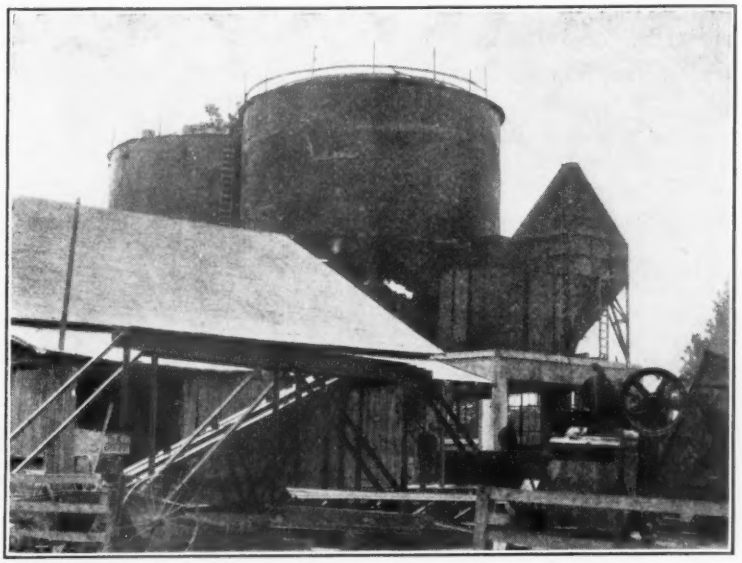

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There is greater satisfaction in knowing that the frit is *uniformly* fine and that the service is *consistently* dependable.

When you buy Lusterlite Frit you buy *product finish insurance.*

CHICAGO VITREOUS ENAMEL PRODUCT CO.
CICERO ILLINOIS

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English China and Ball

TALCS
for
HEATING ELEMENTS
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Ceramic Specialties Include
Whiting : Paris White : Magnesite
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HAMMILL & GILLESPIE, INC.
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FINEST POTTERY CLAYS

Abrasives (Alundum-Crystolon)
Chicago Vitreous Enamel Product Co.
Ferro Enamel Corp.
Norton Co.

Air Conditioning Systems
Simplex Eng. Co.

Alozite (Refractory Products)
Carborundum Co.
Chicago Vitreous Enamel Product Co.

Alumina (Hydrate and Calcined)
Ceramic Color & Chemical Mfg. Co.
Drakenfeld & Co., B. F.
The Hommel Co., O., Inc.
Jungmann & Co., Inc.
The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.

Aluminum Oxide (Fused)
The Exolon Co.
The Hommel Co., O., Inc.
Norton Co.
The Vitro Mfg. Co.

Alundum (Refractory Products)
Norton Co.

Ammonium Bifluoride
Drakenfeld & Co., B. F.
The Hommel Co., O., Inc.
Jungmann & Co., Inc.
The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.

Ammonium Carbonate
Ceramic Color & Chemical Mfg. Co.
Drakenfeld & Co., B. F.
The Hommel Co., O., Inc.
The Roessler & Hasslacher Chemical Co.

Antimony Oxide
Ceramic Color & Chemical Mfg. Co.
Drakenfeld & Co., B. F.
The Hommel Co., O., Inc.
The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.

Arches (Interlocking, Suspending, and Circular)
Simplex Eng. Co.

Ball Mills
Ceramic Color & Chemical Mfg. Co.
Chicago Vitreous Enamel Product Co.
The Hommel Co., O., Inc.
McDanel Refractory Porcelain Co.
The Vitro Mfg. Co.

Ball Mills (Laboratory Type)
Ceramic Color & Chemical Mfg. Co.
Chicago Vitreous Enamel Product Co.
Denver Fire Clay Co.
The Hommel Co., O., Inc.
The Vitro Mfg. Co.

Barium Carbonate
Ceramic Color & Chemical Mfg. Co.
Drakenfeld & Co., B. F.
Hammill & Gillespie, Inc.
The Hommel Co., O., Inc.
The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.

Batch Systems
Simplex Eng. Co.
Simpson Foundry & Eng. Co.

Batts
Carborundum Co. (*"Carbofrax Aloxite"*)
Denver Fire Clay Co.
Norton Co. (*Alundum Crystolon*)

Bitstone
Consolidated Feldspar Corp.
Potters Supply Co.

Blocks (Refractory)
Carborundum Co.
Chicago Vitreous Enamel Product Co.
Denver Fire Clay Co.
Norton Co.
Pittsburgh Plate Glass Co.
The Vitro Mfg. Co.

Borax
American Potash & Chemical Co.
Denver Fire Clay Co.
Drakenfeld & Co., B. F.
The Hommel Co., O., Inc.
Pacific Coast Borax Co.
The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.

Borax Glass
American Potash and Chemical Corp.
Ceramic Color & Chemical Mfg. Co.
Denver Fire Clay Co.
Drakenfeld & Co., B. F.
The Hommel Co., O., Inc.
Pacific Coast Borax Co.
The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.

Boric Acid (Anhydrous)
Denver Fire Clay Co.
Drakenfeld & Co., B. F.
The Hommel Co., O., Inc.
Pacific Coast Borax Co.
The Vitro Mfg. Co.

Boric Acid (Crystal, Granular, or Powder)
American Potash & Chemical Corp.
Ceramic Color & Chemical Mfg. Co.
Denver Fire Clay Co.
Drakenfeld & Co., B. F.
The Hommel Co., O., Inc.
Pacific Coast Borax Co.
The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.

Boron Carbide
Norton Co.

Brick (Refractory)
Carborundum Co. (*"Carbofrax Aloxite"*)
Chicago Vitreous Enamel Product Co.
Denver Fire Clay Co.
Norton Co.
The Vitro Mfg. Co.

Carbofrax (Refractory Products)
Carborundum Co.
Chicago Vitreous Enamel Product Co.

Carbolon (Refractory Products)
The Exolon Co.

Carbonates (Barium, Lead)
Ceramic Color & Chemical Mfg. Co.
Drakenfeld & Co., B. F.
The Hommel Co., O., Inc.
The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.

Castings (Abrasive Resisting)
Bethlehem Steel Corp.

Castings for Molds and Plungers
Simpson Foundry & Eng. Co.

Caustic Soda
Ceramic Color & Chemical Mfg. Co.
Denver Fire Clay Co.
The Hommel Co., O., Inc.
Pittsburgh Plate Glass Co.
The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.

Cements
Carborundum Co.
Chicago Vitreous Enamel Product Co.
Norton Co.
Pittsburgh Plate Glass Co.

Ceramic Chemicals
Ceramic Color & Chemical Mfg. Co.
Drakenfeld & Co., B. F.
The Hommel Co., O., Inc.
Jungmann & Co., Inc.
Metal & Thermit Corp.
The Roessler & Hasslacher Chemical Co.
Titanium Alloy Mfg. Co.
The Vitro Mfg. Co.

Chromium Oxide
Ceramic Color & Chemical Mfg. Co.
Drakenfeld & Co., B. F.
Ferro Enamel Corp.
The Hommel Co., O., Inc.
The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.

Clay (Ball)
Ceramic Color & Chemical Mfg. Co.
Hammill & Gillespie, Inc.
The Hommel Co., O., Inc.
Kentucky-Tennessee Clay Co.
Paper Makers Importing Co.
Potters Supply Co.
The Roessler & Hasslacher Chemical Co.
Spinks Clay Co., H. C.
The Vitro Mfg. Co.

Clay (China)
Ceramic Color & Chemical Mfg. Co.
Consolidated Feldspar Corp.
Edgar Brothers Co.
Hammill & Gillespie, Inc.
The Hommel Co., O., Inc.
Paper Makers Importing Co.
The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.

Clay (Electrical, Porcelain)
Ceramic Color & Chemical Mfg. Co.
Edgar Brothers Co.
Hammill & Gillespie, Inc.
Kentucky-Tennessee Clay Co.
Spinks Clay Co., H. C.

Clay (Enamel)
Ceramic Color & Chemical Mfg. Co.
Chicago Vitreous Enamel Product Co.
Edgar Brothers Co.
Ferro Enamel Corp.
Hammill & Gillespie, Inc.
The Hommel Co., O., Inc.
Kentucky-Tennessee Clay Co.
Metal & Thermit Corp.
Paper Makers Importing Co.
Porcelain Enamel & Mfg. Co.
The Roessler & Hasslacher Chemical Co.
Spinks Clay Co., H. C.
Titanium Alloy Mfg. Co.
The Vitro Mfg. Co.

Clay (Fire)
Chicago Vitreous Enamel Product Co.
Denver Fire Clay Co.
Edgar Brothers Co.
Kentucky-Tennessee Clay Co.
Paper Makers Importing Co.
Pittsburgh Plate Glass Co.
Potters Supply Co.

Clay (German Vallendar)
Ceramic Color & Chemical Mfg. Co.
Chicago Vitreous Enamel Product Co.
Ferro Enamel Corp.
Hammill & Gillespie, Inc.
The Hommel Co., O., Inc.
Jungmann & Co., Inc.
Porcelain Enamel & Mfg. Co.
The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.

Clay Miners
Edgar Brothers Co.
Kentucky-Tennessee Clay Co.
Paper Makers Importing Co.
Spinks Clay Co., H. C.

Clay (Potters)
Denver Fire Clay Co.
Hammill & Gillespie, Inc.
The Hommel Co., O., Inc.
Paper Makers Importing Co.
Spinks Clay Co., H. C.

Clay (Process Equipment)
Bonnot Co.

Clay (Sagger)
Edgar Brothers Co.
The Hommel Co., O., Inc.
Kentucky-Tennessee Clay Co.
Paper Makers Importing Co.
Pittsburgh Plate Glass Co.
Potters Supply Co.
Spinks Clay Co., H. C.

Clay (Wad)
Kentucky-Tennessee Clay Co.
Potters Supply Co.
Spinks Clay Co., H. C.

Clay (Wall Tile)
Hammill & Gillespie, Inc.
Kentucky-Tennessee Clay Co.
Paper Makers Importing Co.
Spinks Clay Co., H. C.

Clocks (Gauge Board)
Chicago Vitreous Enamel Product Co.
Ferro Enamel Corp.
The Hommel Co., O., Inc.

Cobalt Oxide
Ceramic Color & Chemical Mfg. Co.
Drakenfeld & Co., B. F.
Ferro Enamel Corp.
The Hommel Co., O., Inc.
Jungmann & Co., Inc.
The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.

Colors
Ceramic Color & Chemical Mfg. Co.
Chicago Vitreous Enamel Product Co.
Drakenfeld & Co., B. F.
Ferro Enamel Corp.
The Hommel Co., O., Inc.
Pittsburgh Plate Glass Co.
The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.

Cones
The Edward Orton, Jr., Ceramic Foundation

Conveying Equipment
Simplex Eng. Co.
Simpson Foundry & Eng. Co.

Cornwall Stone (Imported)
Consolidated Feldspar Corp.
Drakenfeld & Co., B. F.
Hammill & Gillespie, Inc.
The Hommel Co., O., Inc.
Paper Makers Importing Co.
The Roessler & Hasslacher Chemical Co.

Crucibles (Filter, Melting, Ignition)
Denver Fire Clay Co.
Norton Co.
Pittsburgh Plate Glass Co.
Potters Supply Co.

Crystolon (Refractory Products)
Norton Co.

Cullet, Washing Plants, Incinerators, Crushers
Simplex Eng. Co.
Simpson Foundry & Eng. Co.

Decorating Supplies
Ceramic Color & Chemical Mfg. Co.
Chicago Vitreous Enamel Product Co.
Drakenfeld & Co., B. F.
The Hommel Co., O., Inc.
Pittsburgh Plate Glass Co.

The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.

Drying Machinery
Ferro Enamel Corp.

Enameling Equipment (Complete)
Ceramic Color & Chemical Mfg. Co.
Chicago Vitreous Enamel Product Co.
Ferro Enamel Corp.
The Hommel Co., O., Inc.
Porcelain Enamel & Mfg. Co.

Enameling Furnaces
Carborundum Co. (*Carboradiant*)
Ceramic Color & Chemical Mfg. Co.
Chicago Vitreous Enamel Product Co.
Ferro Enamel Corp.
The Hommel Co., O., Inc.
Norton Co.
Porcelain Enamel & Mfg. Co.

Enameling Iron (Sheet)
American Rolling Mill Co.

Enameling Muffles
Carborundum Co. (*Carbofrax*)
Chicago Vitreous Enamel Product Co.
Ferro Enamel Corp.
Norton Co. (*Alundum*)
Pittsburgh Plate Glass Co.

Enameling (Practical Service)
Ceramic Color & Chemical Mfg. Co.
Chicago Vitreous Enamel Product Co.
Ferro Enamel Corp.
The Hommel Co., O., Inc.
Metal & Thermit Corp.
Porcelain Enamel & Mfg. Co.
Titanium Alloy Mfg. Co.
The Vitro Mfg. Co.

Enamels
Ceramic Color & Chemical Mfg. Co.
Chicago Vitreous Enamel Product Co.
The Hommel Co., O., Inc.
Metal & Thermit Corp.
Pittsburgh Plate Glass Co.
The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.

Enamels (Porcelain)
Ceramic Color & Chemical Mfg. Co.
Chicago Vitreous Enamel Product Co.
Ferro Enamel Corp.
The Hommel Co., O., Inc.
Metal & Thermit Corp.
Porcelain Enamel & Mfg. Co.
Titanium Alloy Mfg. Co.
The Vitro Mfg. Co.

Equipment (Porcelain Enameling)
Ceramic Color & Chemical Mfg. Co.
Chicago Vitreous Enamel Product Co.
Ferro Enamel Corp.
The Hommel Co., O., Inc.
Porcelain Enamel & Mfg. Co.

Exolon (Refractory Products)
Ferro Enamel Corp.
The Exolon Co.

Feldspar
Ceramic Color & Chemical Mfg. Co.
Consolidated Feldspar Corp.
Ferro Enamel Corp.
The Hommel Co., O., Inc.
Paper Makers Importing Co.
The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.

Finishing Tools
Simpson Foundry & Eng. Co.

Fire Brick
Carborundum Co.
Denver Fire Clay Co.
Ferro Enamel Corp.
Norton Co.

Fire-Polishing Machines
Simpson Foundry & Eng. Co.

Flint
Ceramic Color & Chemical Mfg. Co.
Consolidated Feldspar Corp.
The Hommel Co., O., Inc.
Paper Makers Importing Co.
The Roessler & Hasslacher Chemical Co.

Flint Pebbles
Chicago Vitreous Enamel Product Co.
Consolidated Feldspar Corp.
Ferro Enamel Corp.
The Hommel Co., O., Inc.

Floors (Non-Slip)
Norton Co.

French Flint
Consolidated Feldspar Corp.
Paper Makers Importing Co.

Frit
Allied Engineering Co.
Ceramic Color & Chemical Mfg. Co.
Chicago Vitreous Enamel Product Co.
Ferro Enamel Corp.
The Hommel Co., O., Inc.
Metal & Thermit Corp.
Porcelain Enamel & Mfg. Co.
Titanium Alloy Mfg. Co.
The Vitro Mfg. Co.

Fuel Oil Systems and Control, Stokers
Simplex Eng. Co.

Furnaces
Allied Engineering Co.
Carborundum Co. (*Carboradiant*)
Chicago Vitreous Enamel Product Co.
Denver Fire Clay Co.
Ferro Enamel Corp.
The Hommel Co., O., Inc.
Porcelain Enamel & Mfg. Co.

Glass Bending Ovens, Glass Decorating Machines
Simplex Eng. Co.

Glass Equipment
Hartford-Empire Co.
Simpson Foundry & Eng. Co.

Glass Melting Tanks and Furnaces
Simplex Eng. Co.

Glass Thickness Gauge
Bausch & Lomb Optical Co.

Glaze and Body Spar
Ceramic Color & Chemical Mfg. Co.
Consolidated Feldspar Corp.
Ferro Enamel Corp.
The Hommel Co., O., Inc.
Paper Makers Importing Co.
The Roessler & Hasslacher Chemical Co.

Glazes and Enamels
Ceramic Color & Chemical Mfg. Co.
Chicago Vitreous Enamel Product Co.
Drakenfeld & Co., B. F.
Ferro Enamel Corp.
The Hommel Co., O., Inc.
Metal & Thermit Corp.
Porcelain Enamel & Mfg. Co.
The Roessler & Hasslacher Chemical Co.
Titanium Alloy Mfg. Co.
The Vitro Mfg. Co.

Glaze Spar
Ceramic Color & Chemical Mfg. Co.
Consolidated Feldspar Corp.
The Hommel Co., O., Inc.
Paper Makers Importing Co.
The Roessler & Hasslacher Chemical Co.

Goggles
Willson Products, Inc.

Gold
Ceramic Color & Chemical Mfg. Co.
Drakenfeld & Co., B. F.
The Hommel Co., O., Inc.
The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.

Grinding Mills
Simpson Foundry & Eng. Co.

Grinding Wheels
Norton Co. (*Alundum Crystolon*)

Hearths
Carborundum Co.
(*Carbofrax* heat treating)
Norton Co. (*Crystolon*)

Hearths (High Aluminous Clay, Electrically Sintered Aluminum Oxide, Silicon Carbide)
Carborundum Co.
Norton Co.

Iron (Enameling)
American Rolling Mill Co.

Iron Oxide
Ceramic Color & Chemical Mfg. Co.
Drakenfeld & Co., B. F.
The Hommel Co., O., Inc.
The Vitro Mfg. Co.

Kaolin
Ceramic Color & Chemical Mfg. Co.
Consolidated Feldspar Corp.
Edgar Brothers Co.
Hammill & Gillespie, Inc.
The Hommel Co., O., Inc.
Paper Makers Importing Co.

Kettles of All Kinds
Simpson Foundry & Eng. Co.

Kilns, China (Decorating)
Allied Engineering Co.
Denver Fire Clay Co.
Drakenfeld & Co., B. F.
The Hommel Co., O., Inc.

Kryolith
Ceramic Color & Chemical Mfg. Co.
The Hommel Co., O., Inc.
Jungmann & Co.,Inc.
The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.

Ladles (Cast-iron)
Simpson Foundry & Eng. Co.

Leeds (High Aluminous Clay, Electrically Sintered Aluminum Oxide, Silicon Carbide)
Carborundum Co.

Lehrs
Simpson Foundry & Eng. Co.

Lehrs (Electric or Fuel Heated)
Simplex Eng. Co.

Lehr Loaders
Simpson Foundry & Eng. Co.

Linings (Furnace Refractory, Block Refractory Plate, Brick and Tile)
Carborundum Co.
Chicago Vitreous Enamel Product Co.
Denver Fire Clay Co.
Norton Co.
Pittsburgh Plate Glass Co.
The Vitro Mfg. Co.

Magnesia (Sintered, Calcined)
Drakenfeld & Co., B. F.
The Exolon Co.
The Hommel Co., O., Inc.
Jungmann & Co. Inc.
Norton Co.

Magnesite
Ceramic Color & Chemical Mfg. Co.
Drakenfeld & Co., B. F.
Hammill & Gillespie, Inc.
The Hommel Co., O., Inc.

Manganese
Ceramic Color & Chemical Mfg. Co.
Drakenfeld & Co., B. F.
Hammill & Gillespie, Inc.
The Hommel Co., O., Inc.
The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.

Manganese (Oxide)
The Roessler & Hasslacher Chemical Co.

Masks (Breathing)
Willson Products, Inc.

Metals (Porcelain Enameling)
American Rolling Mill Co.

Microscopes (Polarizing)
Bausch & Lomb Optical Co.

Minerals
Ceramic Color & Chemical Mfg. Co.
Drakenfeld & Co., B. F.
The Hommel Co., O., Inc.
The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.

Muffles (Furnace)
Allied Engineering Co.
Carborundum Co. (*Carbofrax*)
Chicago Vitreous Enamel Product Co.
Denver Fire Clay Co.
Ferro Enamel Corp.
Norton Co.
Pittsburgh Plate Glass Co.

Mullite (Artificial)
The Exolon Co.

Muriatic Acid
Denver Fire Clay Co.
The Hommel Co., O., Inc.

Nitrates (Cobalt, Sodium)
Ceramic Color & Chemical Mfg. Co.
Drakenfeld & Co., B. F.
The Hommel Co., O., Inc.
The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.

Norbide (Norton Boron Carbide)
Norton Co.

Olivine
The Roessler & Hasslacher Chemical Co.

Opacifiers
Ceramic Color & Chemical Mfg. Co.
The Hommel Co., O., Inc.
Jungmann & Co., Inc.
Metal & Thermit Corp
Porcelain Enamel & Mfg. Co.
The Roessler & Hasslacher Chemical Co.
Titanium Alloy Mfg. Co.
The Vitro Mfg. Co.

Oxides
Ceramic Color & Chemical Mfg. Co.
Chicago Vitreous Enamel Product Co.
Drakenfeld & Co., B. F.
Ferro Enamel Corp.
The Hommel Co., O., Inc.
Metal & Thermit Corp.
Porcelain Enamel & Mfg. Co.
The Roessler & Hasslacher Chemical Co.
Titanium Alloy Mfg. Co.
The Vitro Mfg. Co.

Pins
Chicago Vitreous Enamel Product Co.
Ferro Enamel Corp.
Potters Supply Co.

Polariscope
Bausch & Lomb Optical Co.
Simpson Foundry & Eng. Co.
Porcelain Enameling Service (Practical)
American Rolling Mill Co.
Ceramic Color & Chemical Mfg. Co.
Chicago Vitreous Enamel Product Co.
Ferro Enamel Corp.
The Hommel Co., O., Inc.
Jungmann & Co., Inc.
Porcelain Enamel & Mfg. Co.
Titanium Alloy Mfg. Co.
The Vitro Mfg. Co.
Porcelain Enamels
Ceramic Color & Chemical Mfg. Co.
Chicago Vitreous Enamel Product Co.
Ferro Enamel Corp.
The Hommel Co., O., Inc.
Metal & Thermit Corp.
Porcelain Enamel & Mfg. Co.
The Roessler & Hasslacher Chemical Co.
Titanium Alloy Mfg. Co.
The Vitro Mfg. Co.
Potash (Carbonate)
Ceramic Color & Chemical Mfg. Co.
The Hommel Co., O., Inc.
Jungmann & Co., Inc.
The Roessler & Hasslacher Chemical Co.
Solvay Sales Corp.
The Vitro Mfg. Co.
Pot-setting Tools
Simpson Foundry & Eng. Co.
Presses, Side-lever and Bench
Simpson Foundry & Eng. Co.
Producer Glass Plants
Simplex Eng. Co.
Pyrometer Tubes (Refractory and Hard Porcelain)
Denver Fire Clay Co.
McDanel Refractory Porcelain Co.
Norton Co.
Pyrometric Cones
The Edward Orton, Jr., Ceramic Foundation

Raw Material Handling Equipment
Simpson Foundry & Eng. Co.
Refractometers
Bausch & Lomb Optical Co.
Refractories
Carborundum Co.
Denver Fire Clay Co.
The Exolon Co.
Norton Co.
Pittsburgh Plate Glass Co.
Refractory Materials
Carborundum Co.
Chicago Vitreous Enamel Product Co.
Denver Fire Clay Co.
The Exolon Co.
Kentucky-Tennessee Clay Co.
Norton Co.
Pittsburgh Plate Glass Co.
Titanium Alloy Mfg. Co.
Respirators
Willson Products, Inc.
Rutile
Ceramic Color & Chemical Mfg. Co.
Drakenfeld & Co., B. F.
The Hommel Co., O., Inc.
Metal & Thermit Corp.
The Roessler & Hasslacher Chemical Co.
Titanium Alloy Mfg. Co.
The Vitro Mfg. Co.

Saggers
Carborundum Co.
Norton Co.
Potters Supply Co.
Salt Cake
American Potash & Chemical Co.
Saponin
Jungmann & Co., Inc.
Selenite of Sodium
Drakenfeld & Co., B. F.
The Hommel Co., O., Inc.
The Vitro Mfg. Co.
Selenium
Ceramic Color & Chemical Mfg. Co.
Drakenfeld & Co., B. F.
The Hommel Co., O., Inc.
The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.
Sheets (Enameling Iron)
American Rolling Mill Co.
Silica (Fused)
The Exolon Co.
The Hommel Co., O., Inc.
Silicate of Soda
Ceramic Color & Chemical Mfg. Co.
Denver Fire Clay Co.
The Hommel Co., O., Inc.
Philadelphia Quartz Co.
Silicon Carbide
The Exolon Co.
Norton Co.
Silicon Carbide Firesand
The Exolon Co.
Sillimanite (Synthetic)
The Exolon Co.
Pittsburgh Plate Glass Co.
Slabs (Furnace)
Carborundum Co.
Norton Co.
Smelters
Ferro Enamel Corp.
Porcelain Enamel & Mfg. Co.
Soda Ash
American Potash and Chemical Corp.
Ceramic Color & Chemical Mfg. Co.
Denver Fire Clay Co.
The Hommel Co., O., Inc.
Pittsburgh Plate Glass Co.
The Roessler & Hasslacher Chemical Co.
Solvay Sales Corp.
The Vitro Mfg. Co.
Sodium Antimonate
Ceramic Color & Chemical Mfg. Co.
Drakenfeld & Co., B. F.
The Hommel Co., O., Inc.
Metal & Thermit Corp.
The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.
Sodium Fluoride
Ceramic Color & Chemical Mfg. Co.
Denver Fire Clay Co.
Drakenfeld & Co., B. F.
The Hommel Co., O., Inc.
Jungmann & Co., Inc
The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.
Sodium Silica Fluoride
Jungmann & Co.
Soot Blowers
Simpson Foundry & Eng. Co.
Special Machines
Simpson Foundry & Eng. Co.
Spar
Ceramic Color & Chemical Mfg. Co.
Consolidated Feldspar Corp.
The Hommel Co., O., Inc.
Paper Makers Importing Co.
The Roessler & Hasslacher Chemical Co.
Spurs
Potters Supply Co.
Stilts
Potters Supply Co.
Sulfuric Acid
Denver Fire Clay Co.
The Hommel Co., O., Inc.
Talc
Ceramic Color & Chemical Mfg. Co.
Hammill & Gillespie, Inc.
The Hommel Co., O., Inc.
Paper Makers Importing Co.
The Roessler & Hasslacher Chemical Co.
Tanks (Pickle)
Chicago Vitreous Enamel Product Co.
Ferro Enamel Corp.
Tanks for Raw Material Steel or Concrete
Simpson Foundry & Eng. Co.
Tile (Floor)
Norton Co.
Tile (Muffle)
Norton Co.
Tile (Refractory)
Carborundum Co. (*Carbofrax*)
Chicago Vitreous Enamel Product Co.
Denver Fire Clay Co.
Norton Co.
Pittsburgh Plate Glass Co.
Tile (Wall)
Denver Fire Clay Co.
Ferro Enamel Corp.
Tin Oxide
Ceramic Color & Chemical Mfg. Co.
Chicago Vitreous Enamel Product Co.
Drakenfeld & Co., B. F.
The Hommel Co., O., Inc.
Metal & Thermit Corp.
The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.
Titanium
Ceramic Color & Chemical Mfg. Co.
Drakenfeld & Co., B. F.
The Hommel Co., O., Inc.
Titanium Alloy Mfg. Co.
The Vitro Mfg. Co.
Titanium Oxide
Ceramic Color & Chemical Mfg. Co.
Drakenfeld & Co., B. F.
The Hommel Co., O., Inc.
The Roessler & Hasslacher Chemical Co.
Titanium Alloy Mfg. Co.
The Vitro Mfg. Co.
Tubes (Insulating)
McDanel Refractory Porcelain Co.
Norton Co.
Tubes (Pyrometer)
Denver Fire Clay Co.
McDanel Refractory Porcelain Co.
Norton Co.
Pittsburgh Plate Glass Co.

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